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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WARTIME REPORT

WIND-TUNNEL INVESTIGATION OF ALTERNATIVE

PROPELLERS OPERATING BEHIND DEFLECTED

WING FLAPS FOR THE XB-36 AIRPLANE

By Emanuel Boxer

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NACA

WASHINGTON

MR No. L5K12a

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

MEMORANDUM REPORT

for the

Air Technical Service Command, Army Air Forces

WIND-TUNNEL INVESTIGATION OF ALTERNATIVE

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SUMMARY

        Tests have been conducted in the Langley propeller-
research tunnel to determine the aerodynamic character-
istics of two pusher propellers of identical plan form,
but different airfoil sections operating behind a slotted
flap. The tests were made upon a wing-flap-nacelle com-
bination simulating the arrangement at the center nacelle
of the XB-36 airplane. Conditions at the inboard nacelle
were simulated for several tests by adding a model of the
landing gear.

        Tests were made over the range of blade angles and
flap deflections necessary to cover all flight conditions
of the subject airplane.

        The propellers, one embodying NACA 16-series sec-
tions, the other Clark Y, exhibited very similar effici-
encies within experimental error at low tip speeds for
all flap deflections. The peak efficiency of both pro-
pellers was reduced 2.5 and 6 percent for 20° and 40°
flap angles, respectively. At the take-off power coef-
ficient of 0.055 and estimated take-off flap angle of 20°,
the efficiency loss caused by the flap is slight.

        Extension of the landing gear decreased the maximum
and take-off efficiencies inappreciably for most con-
ditions.

        Compressibility effects at a tip Mach number of 0.94
caused a 4 percent reduction in peak efficiency for the
16-series propeller when operating at a blade angle of 10°.

For the same condition the Clark Y propeller experienced
a 2 percent increase in peak efficiency. .

INTRODUCTION

An investigation of the effects of deflected wing
flaps upon the propulsive efficiency of propellers for
the XB-36 airplane has been made in the Langley propeller-
research tunnel at the request of the Air Technical Service
Command, Army Air Forces.

The Consolidated-Vultee XB-36 airplane is dependent
upon the use of wing flaps to take off in the specified
distance. The effect of the flap wake upon the pusher
propellers was unknown, but a serious impairment of
efficiency was implied by the results of several British
tests. Therefore, a model was built simulating the
center nacelle of the XB-36 airplane which in the interest
of obtaining results as rapidly as possible was provided
with an available low activity-factor propeller with
Clark Y section. Unpublished results obtained with this
configuration proved the feasibility of take-off with the
arrangement of the XB-36 airplane propulsive unit; however,
the correct value of propeller thrust necessary to compute
the take-off distance was not obtained. The efficiency at
any given forward speed varied as much as 10 percent
depending upon the activity-factor correction used. There-
fore, an additional series of tests was made using a model
of the XB-36 propeller (Curtiss 1129-24 embodying NACA
16-series sections). Preliminary tests of this propeller
indicated unsatisfactorily low efficiencies with deflected
flaps which at that time were thought to be due to the
adverse effects of oscillating flow upon the 16-series
section. To determine the effect of blade section,
another propeller of the same plan form but embodying
Clark Y sections was built and tested. The large losses
noted in the preliminary tests were subsequently traced
to variations in the drag of the configuration with pro-
peller removed.

Tests were made over the range of blade angle and
flap deflection to cover all flight conditions of the
XB-36 airplane. Although neither full-scale Reynolds
number nor blade wake-passage frequency could be
duplicated for these tests, the distribution of Mach

number along the blade was obtained at a blade angle lower
than that for take-off to determine the Mach number effects
upon the propulsive efficiency.

APPARATUS AND METHODS

The model consisted of a constant-chord wing with
nacelle and flap simulating the arrangement at the
center nacelle of the XB-36 airplane. (See figs. 1
and 2.) The scale of the model (4/19) was selected on a
basis of the propeller available for the preliminary tests.
A wing span of 15 feet was selected to prevent tip effects
from influencing the results. The single-slotted flap
was used throughout the present series of tests because
the optimum design of a double-slotted flap had not yet
been obtained. The extended landing gear simulating
conditions at the inboard nacelle was used for several
of the tests. Because of uncertainty of the final design,
the nacelle nose was faired to meet the wing, omitting
the air inlet in the nose of the nacelle. The exit-air
slot at the juncture of the nacelle and spinner was
faired over. Proposed propeller cuffs were not employed.

The 4-foot-diameter model propellers, the blade-
form curves of which are given in figure 3, are of
identical plan form (fig. 4) but differ in airfoil sec-
tion and pitch distribution. The Curtiss 1129 propeller
was designed embodying NACA 16-series sections. The pro-
peller incorporating Clark Y sections was built with a
slight modification of pitch distribution to allow for
the difference in airfoil characteristics. The activity
factor for both blades is 121.

The proposed two-speed propeller drive of the original
power-plant design has been abandoned for structural
reasons in favor of a single-speed reduction. The new
compromise gear ratio is now 0.381 which at the take-off
engine rating yields a power coefficient of 0.055. The
corresponding no-flap take-off advance ratio is reduced
to 0.59.

The thrust of the installation was determined from
the tunnel balance system. To minimize variations of
basic (propeller removed) drag resulting from changes in
wing surface conditions, a strip of linen tape was doped

to the wing surface approximately 5 percent of the chord
from the leading edge. The propeller torque was measured
by a spring-type autosyn-indicating dynamometer.

The testing procedure followed for the present tests
was to operate the propeller at a constant speed prede-
termined for each blade angle, while increasing the tunnel
velocity from 30 to 100 miles per hour. The rotational
speed was selected so that the propeller would operate
near zero thrust at 100 miles per hour. In order to
obtain sufficient test points at blade angles greater
than 25°, the test procedure was as follows: first, the
rotational speed was set at the maximum value obtainable
at a low tunnel airspeed and the tunnel airspeed was
increased to 100 miles per hour; and second, at a tunnel
airspeed of 100 miles per hour the rotational speed was
reduced until zero thrust was obtained.

Tests were made at $0°$ wing angle of attack for flap
angles of $0°$, $10°$, $20°$, $30°$, and $40°$ and for blade angles
varying from $12.5°$ to $25°$ in $2.5°$ increments. Tests were
also made of each propeller with wing flap neutral for $5°$
blade-angle increments from $25°$ to $50°$. Additional tests
were made with flap neutral and at a blade angle of $10°$
in which the propeller rotational tip speed was varied
from 413 to 1040 feet per second. At the latter speed
the Mach number distribution along the blade closely
approximated that of the full-scale propeller at take-
off, although power limitation prevented duplication of
the take-off blade angle.

SYMBOLS

D   propeller diameter, feet

S   wing area, square feet

V   velocity of air stream, feet per second

ρ density of air, slugs per cubic foot

q   dynamic pressure, pounds per square foot $\left(\dfrac{\rho V^2}{2}\right)$

δ_f flap angle, degrees

$\beta_{0.75R}$ blade angle at the 0.75 radius, degrees

n   propeller rotational speed, rps

C_D drag coefficient $\left(\dfrac{Drag}{qS}\right)$

C_L lift coefficient $\left(\dfrac{Lift}{qS}\right)$

J   advance ratio $\left(\dfrac{V}{nD}\right)$

C_P power coefficient $\left(\dfrac{Power}{\rho n^3 D^5}\right)$

C_T thrust coefficient $\dfrac{T_e}{\rho n^2 D^4}$ or $\left(C_{D_c} - C_{D_p}\right)\dfrac{SJ^2}{2D^2}$

T_e effective thrust, obtained by adding the drag of
the model with propeller removed to the
resultant measured horizontal force with
propeller operating at the same stream dynamic
pressure and model lift coefficient

η propulsive efficiency $\left(\dfrac{JC_T}{C_P}\right)$

Subscripts:

c   denotes propeller removed

p   denotes propeller operating

RESULTS AND DISCUSSION

The results of the present investigation are presented in the usual propeller coefficient form of C_T, C_p, and η plotted against the advance ratio J. Results of tests simulating the center nacelle are presented in figures 5 to 8, the landing gear extended or inboard nacelle results in figures 9 and 10.

An indication of the accuracy of the data is shown by the test points in figure 6(a). The curves were faired and cross faired as a family for any one configuration. The necessity for so doing is apparent from the scatter

of the force measurements shown in figure 11. The
propeller-removed drag coefficient used to compute the
thrust is obtained from the wing polar curve at the value
of the propeller operating C_L. However, the large lift
force fluctuations dictate the use of a faired C_L varia-
tion with advance ratio to reduce scatter of C_T test
points. Thus in figure 11 the solid curve is the original
fairing used to compute the test results for the 20° blade
angle of figure 6(a). The dashed curve represents the
change in fairing necessary to attain the cross faired
C_T curve. The maximum divergence between the two curves
occurs at a J of approximately 0.8, with a corresponding
increase in C_{D_c} of 0.0020 or roughly 3 percent in effi-
ciency.

The results of propeller tests with flap neutral
(figs. 5 and 7) may be used directly to determine the
efficiencies for various flight conditions. Except at
extremely high blade angles, the maximum efficiencies of
both propellers can be regarded as equal. In general,
the results of the low-speed tests indicate that the
differences in efficiencies between the Clark Y and
16-series propellers are within experimental error.

Effect of flaps.- A comparison of the peak efficiency
envelopes for the retracted landing-gear condition are
shown in figure 12. At the no-flap take-off advance ratio
of 0.59, the peak efficiency of 79 percent was reduced
2.5 and 6 percent as the flap was deflected to 20° and 40°,
respectively.

For the take-off run computation of the XE-36, the
only valid comparison of effects of flap deflection upon
efficiency or thrust is one at constant power coefficient.
Results obtained by cross-fairing at $C_p = 0.055$ are
shown in figure 13. For a 20° flap angle the efficiencies
of both propellers were only slightly reduced throughout
most of the range of J from 0 to 0.59.

The maximum efficiency (fig. 14) is only slightly
affected by the landing gear. The added decrement of
efficiency caused by flap deflection is of the same
magnitude as with landing-gear retracted. Several smoke
tests made of the flow past the landing wheel indicated
that although somewhat deflected by the flap, a portion
of the wheel wake still entered the propeller disk even
at the maximum flap angle.

The effects of flap deflection at constant power coefficient with landing gear extended are shown in figure 15. The decrease in efficiency is approximately 2 percent for a 20° deflection and 5 percent for a 40° deflection.

The results of the present investigation agree substantially with those of the preliminary unpublished data except at small flap angles with landing gear extended. The previously obtained decrease of 4 to 5 percent in efficiency for flap angles of 20° or less has not been obtained.

Effect of tip Mach number.- The effects of compressibility upon each propeller are shown in figure 16. The increase in thrust and power absorption with increasing tip speed is as anticipated by airfoil theory and verified by previous investigation. (See reference 1.)

The peak efficiency of the propeller with Clark Y sections increased 2 percent and the peak efficiency of the propeller with 16-series sections decreased 4 percent as the tip Mach number was increased from 0.40 to 0.94. One would expect the propeller embodying NACA 16-series sections to possess a higher critical tip Mach number than the Clark Y. This is true at the design condition. However, calculations indicate that at peak efficiency for the low blade angle of 10°, the tip sections are operating near zero C_L indicating large negative peak pressures for the well-cambered 16-series sections and a consequent loss of elemental thrust from early shock. Figure 17 presents an analytical check of these results based on data of reference 2. The efficiency is shown to decrease with Mach number although not as rapidly as is indicated experimentally. However, at the take-off blade angle and flap deflection the blade will be more heavily loaded and the efficiency decrements should be smaller. The Clark Y section does not experience large negative peak pressure near zero lift and, therefore, the propeller exhibits an efficiency gain due to the favorable compressibility effects.

SUMMARY OF RESULTS

The results of this investigation are summarized below:

1. Low-speed test data indicate that except at extremely high blade angles the maximum efficiencies of both propellers can be regarded as equal.

2. At the take-off advance ratio, the peak efficiency of both propellers at the center nacelle was reduced 2.5 and 6 percent for 20° and 40° flap angles, respectively.

3. At the take-off power coefficient of 0.055 and estimated take-off flap angle of 20°, the apparent efficiency loss is within experimental error.

4. Extension of the landing gear decreased the maximum and take-off efficiencies of both propellers slightly for most conditions.

5. At a blade angle lower than that for take-off the compressibility effects at the tip Mach number of 0.94 caused a 4 percent reduction in peak efficiency for the 16-series propellers and an increase of 2 percent for the Clark Y.

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       Compressibility on Eight Full-Scale Propellers
       Operating in the Take-Off and Climbing Range. NACA
       Rep. No. 639, 1938.

2. Stack, John: Tests of Airfoils Designed to Delay the
       Compressibility Burble. NACA Rep. No. 763, 1943.
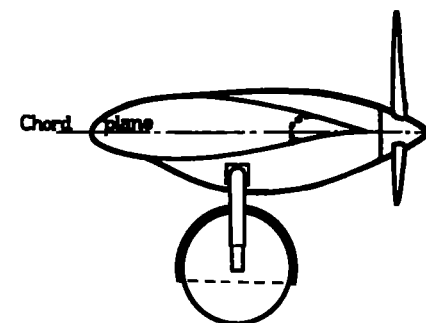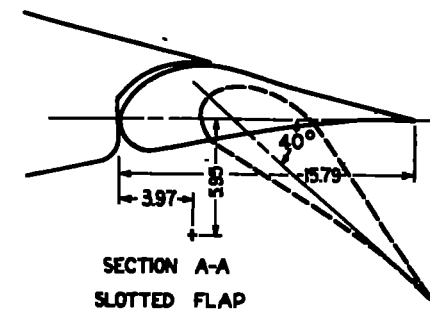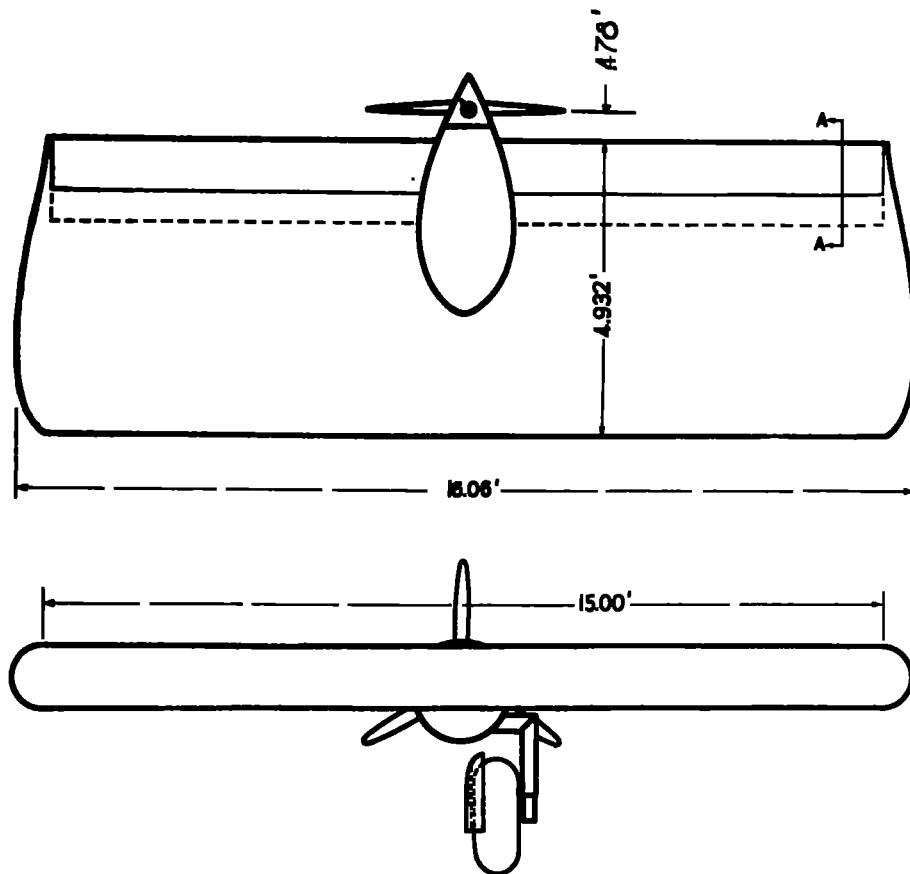
Figure 1.- General arrangement of the XB-36 propeller test model.

(a)   Model prepared for basic drag tests. $\delta_f = 40^\circ$, landing gear retracted.

Figure 2.-   Test setup.
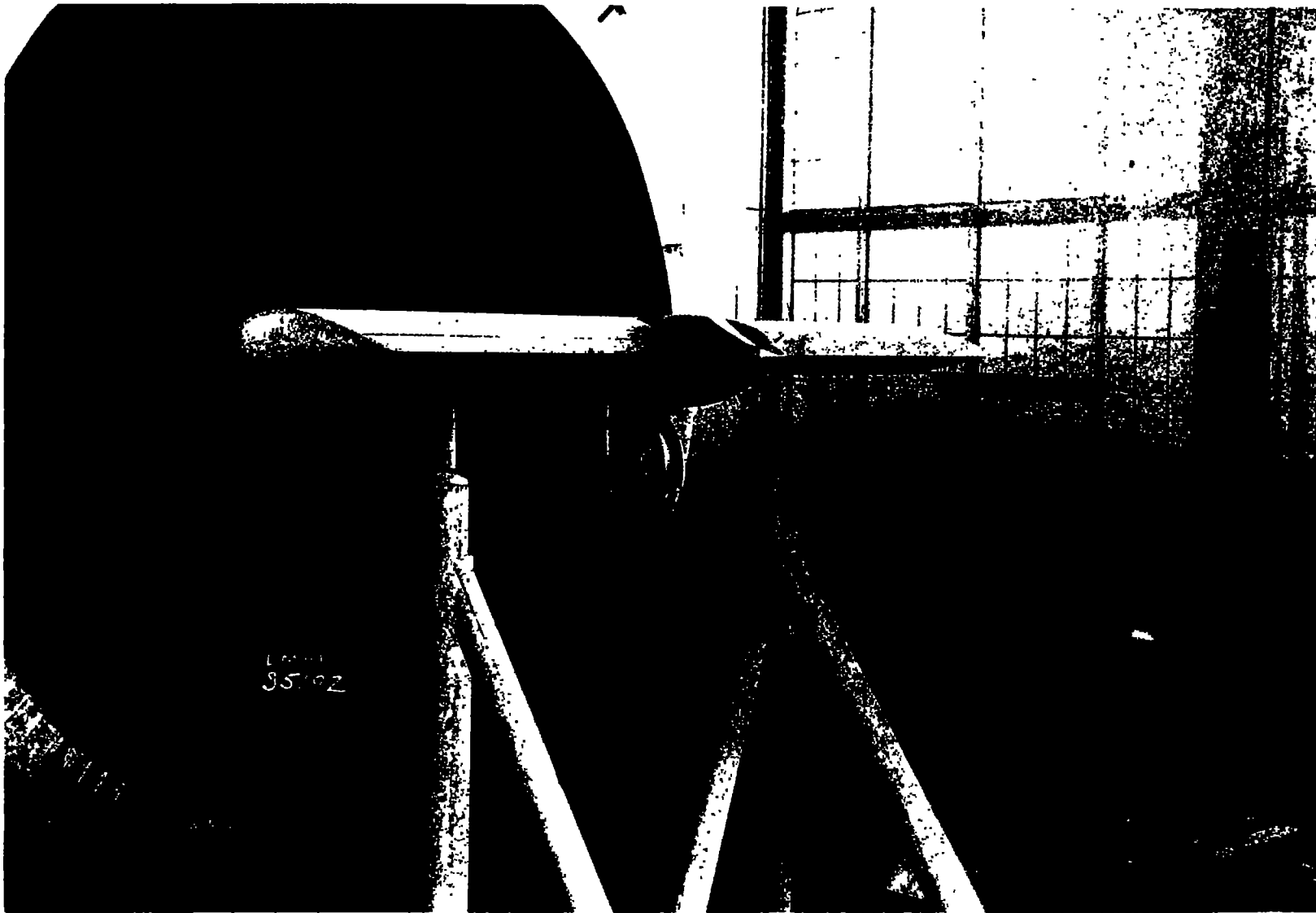
(b) $\delta_f = 0^\circ$, landing gear extended.

Figure 2.- Concluded.
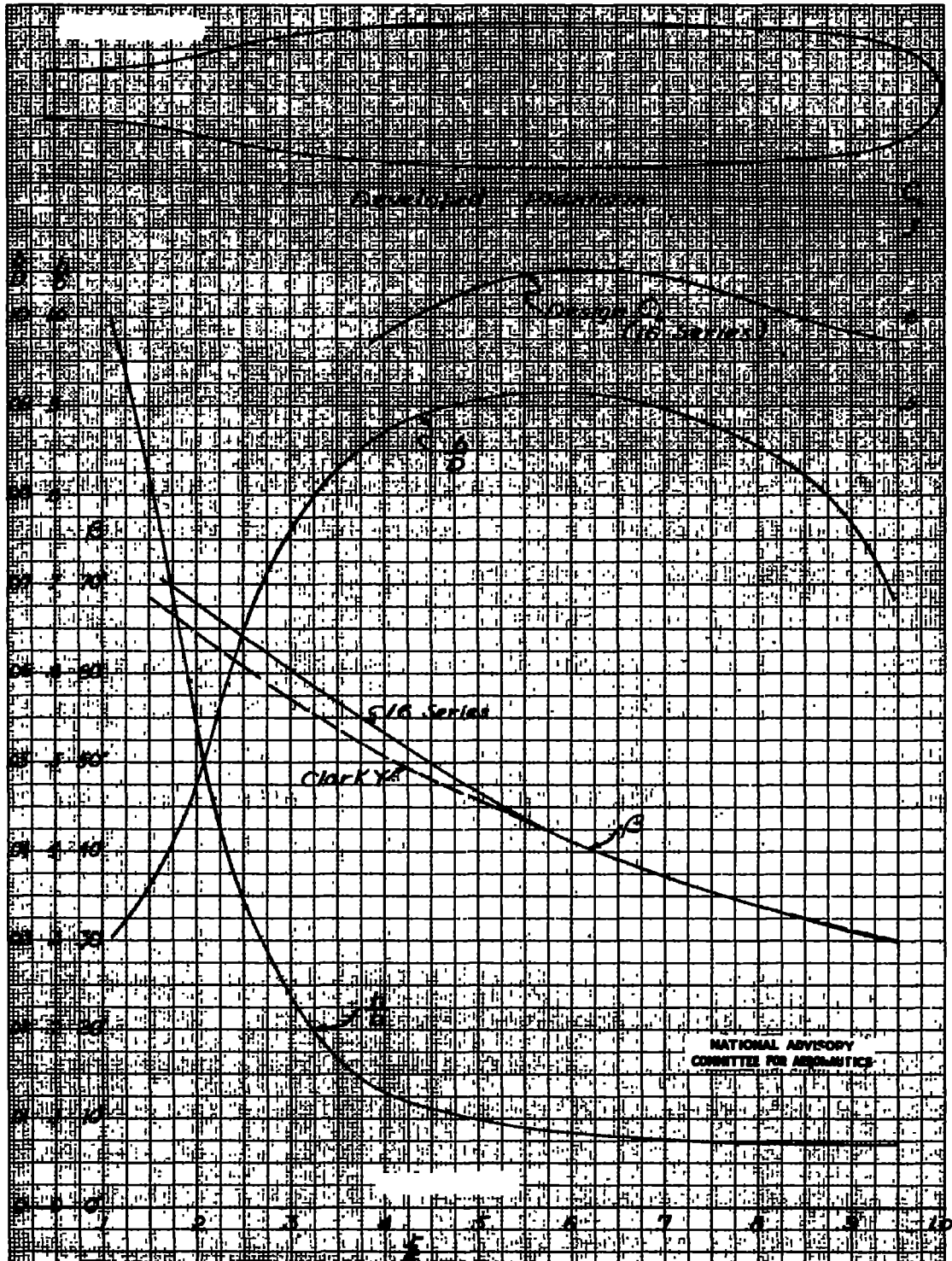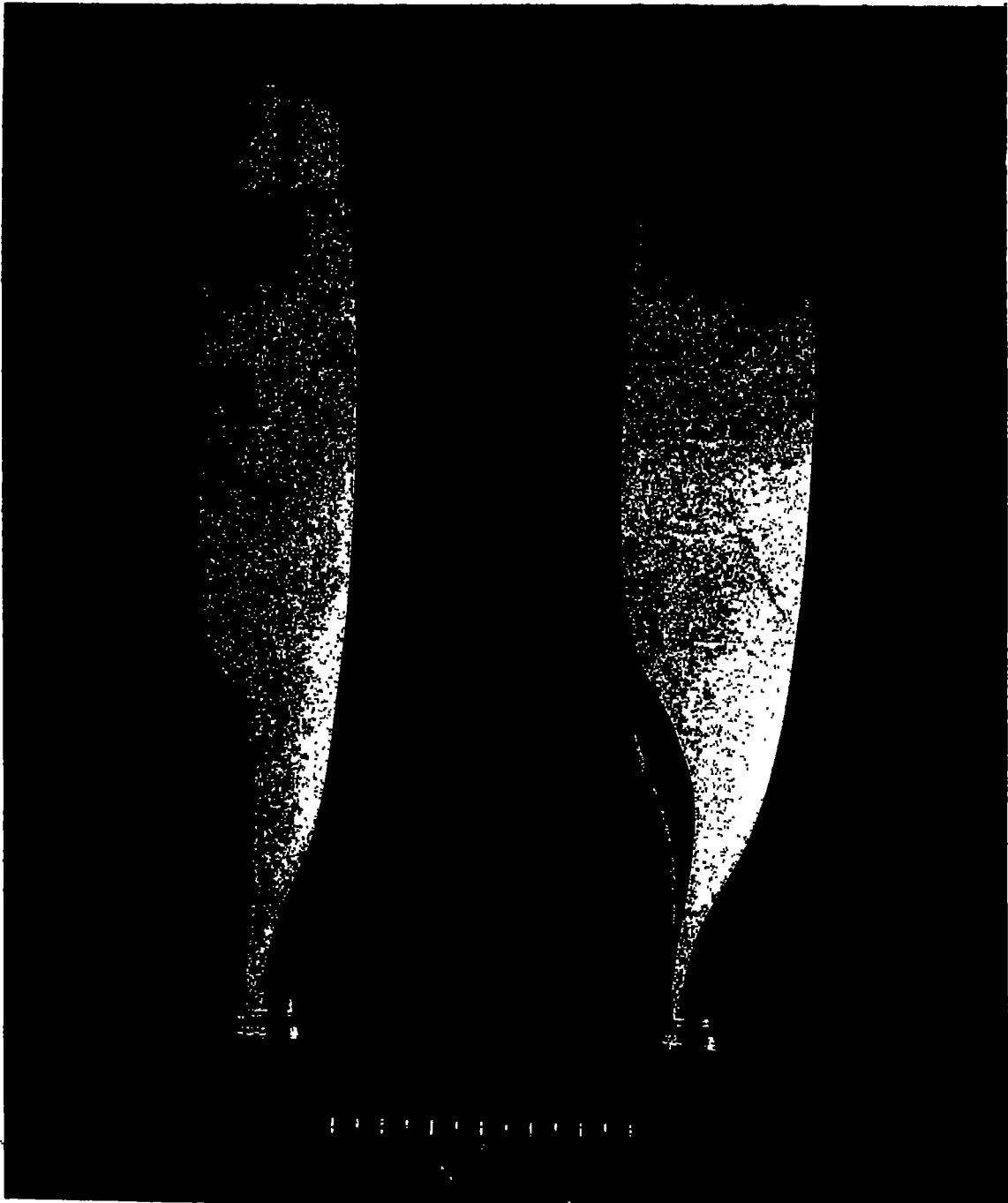
Figure 4.- View of 1129-24 propeller blades, Clark Y left,
16-series right.
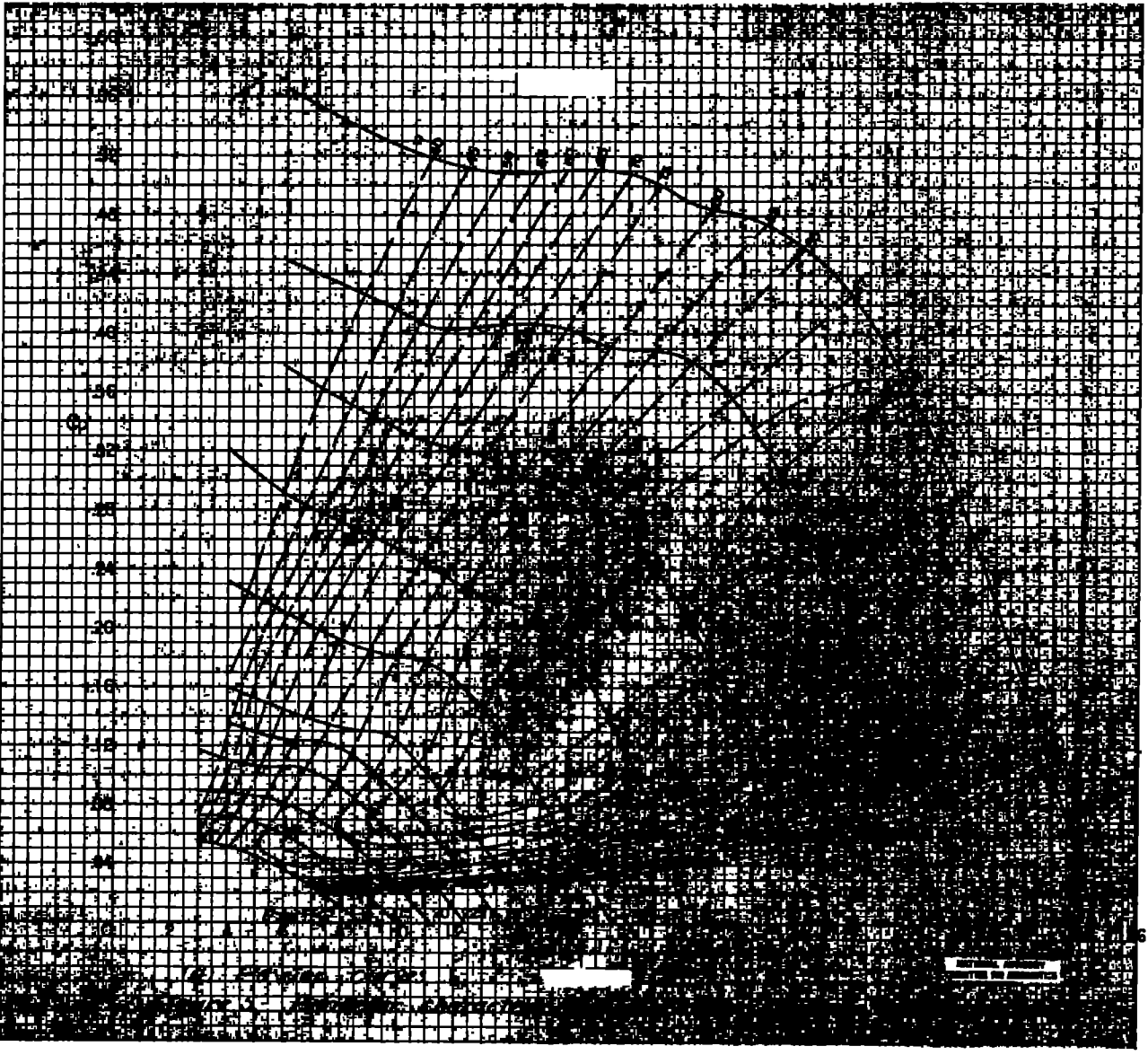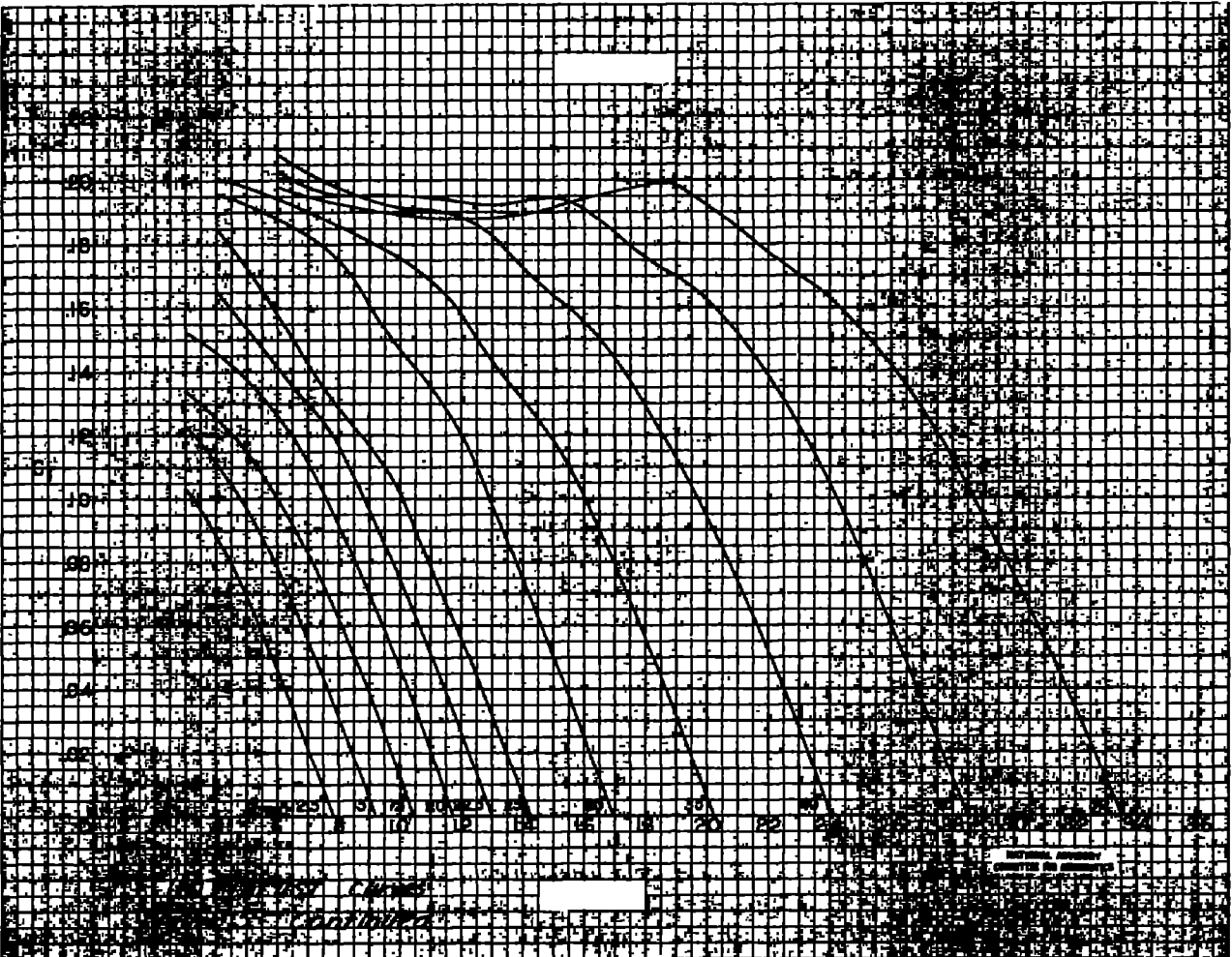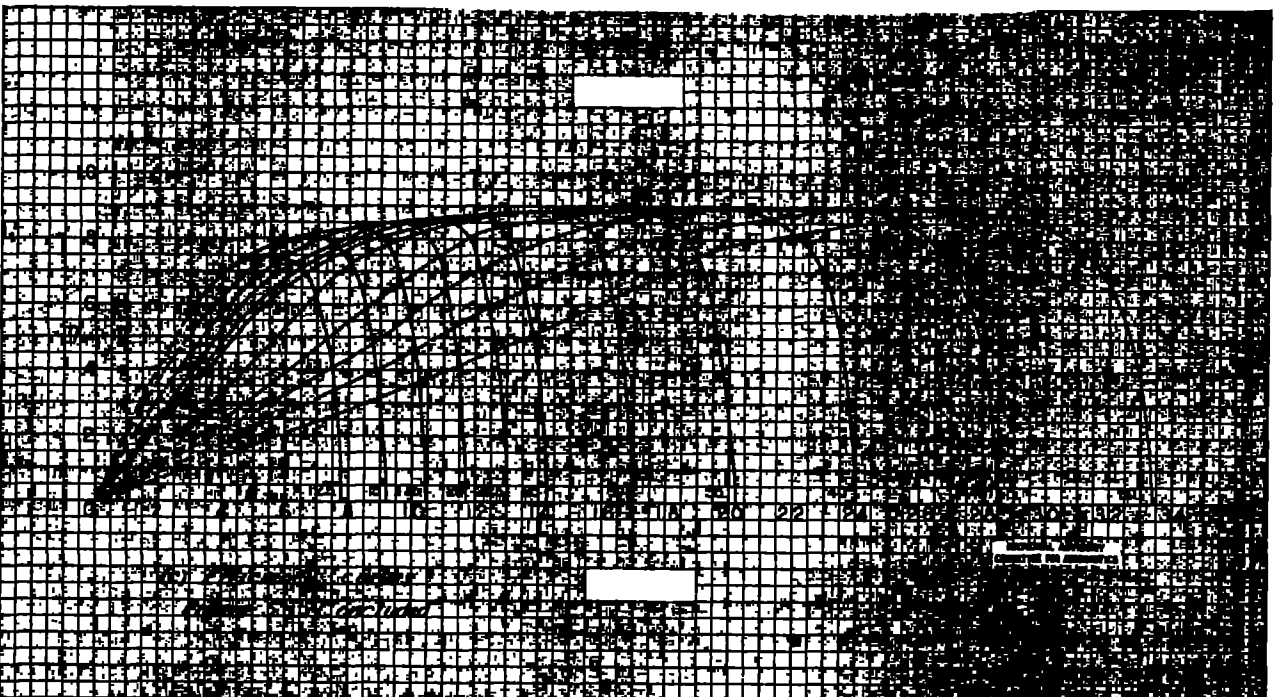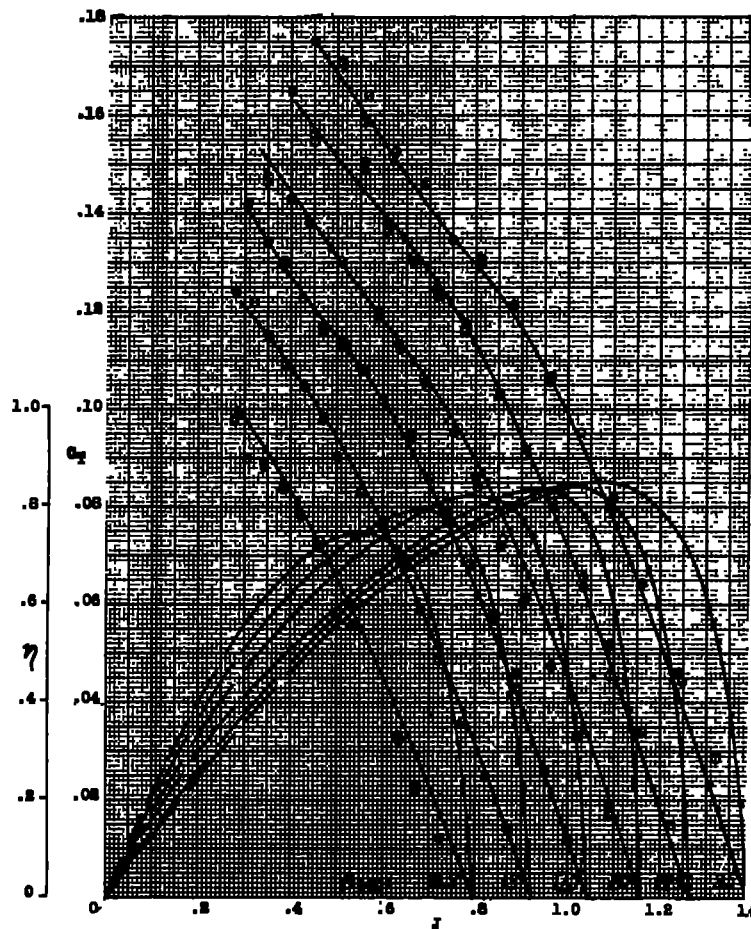
(a) $\delta_f = 10^\circ$

Figure 6.- Propeller characteristics, 16-series, landing gear, gear retracted.

(b) $\delta_T = 20°$
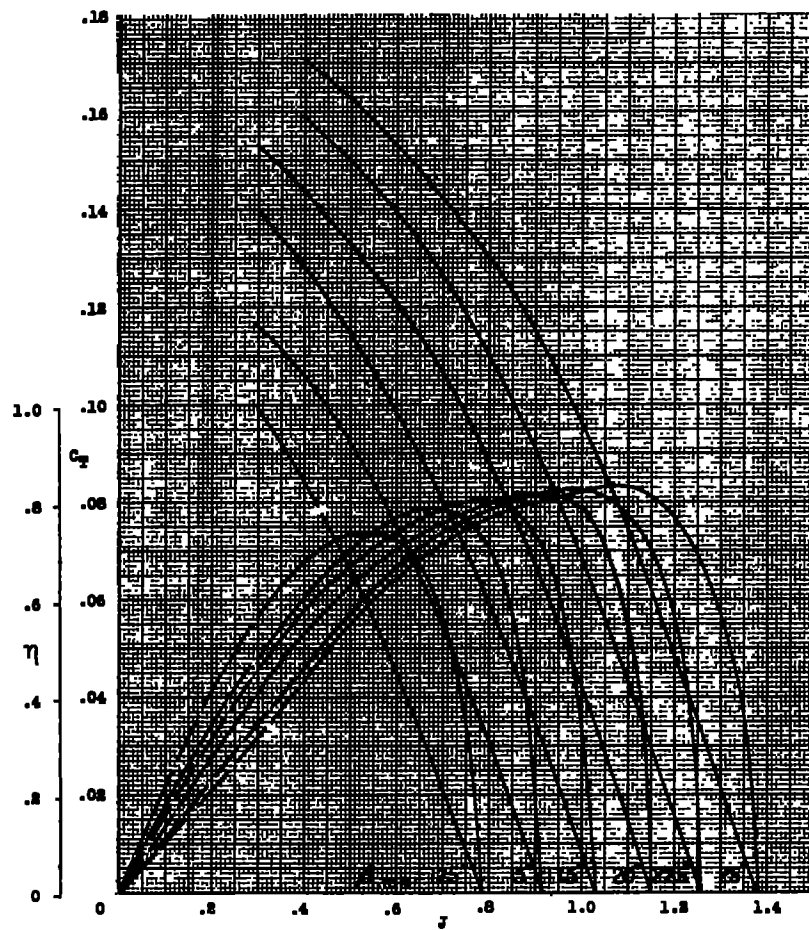
Figure 6.- Continued.

(a) $\delta_f = 30°$

Figure 6.- Continued.

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(a) $\delta_{T} = 40°$

Figure 6.- Concluded.

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(b) Power curves.

Figure 7.- Propeller characteristics. Clark Y section, three blades.

(b) Thrust curves
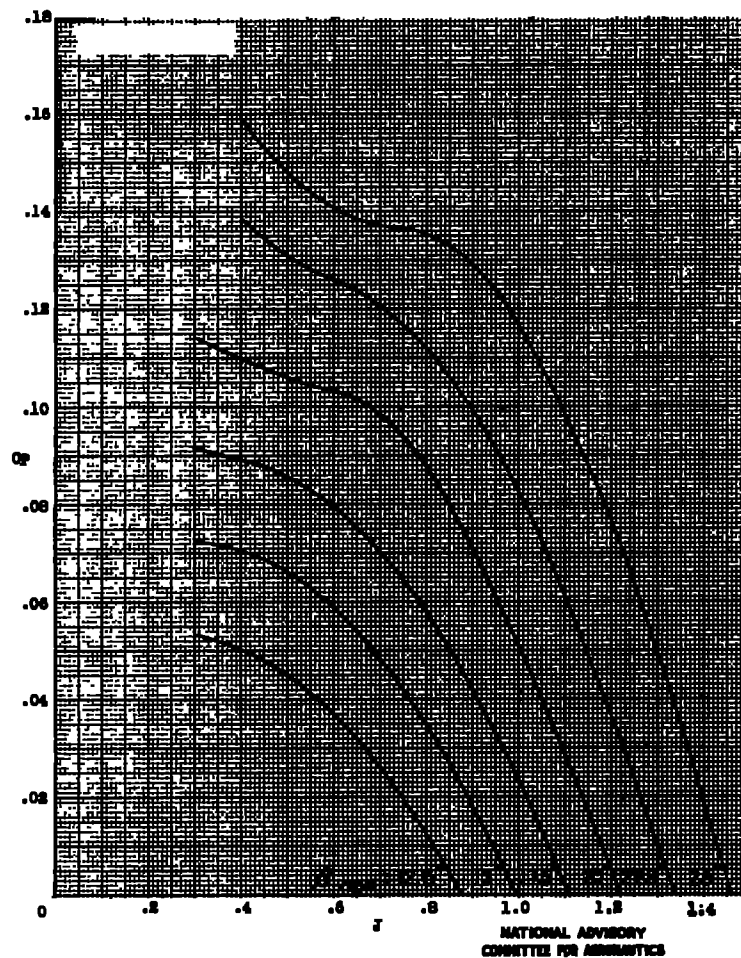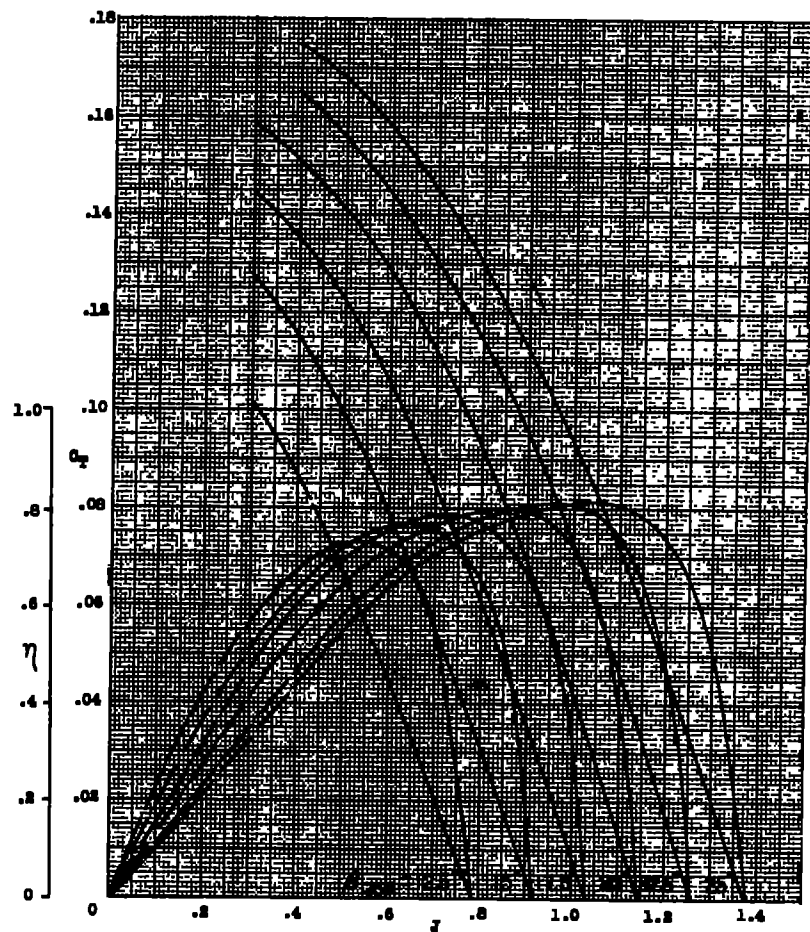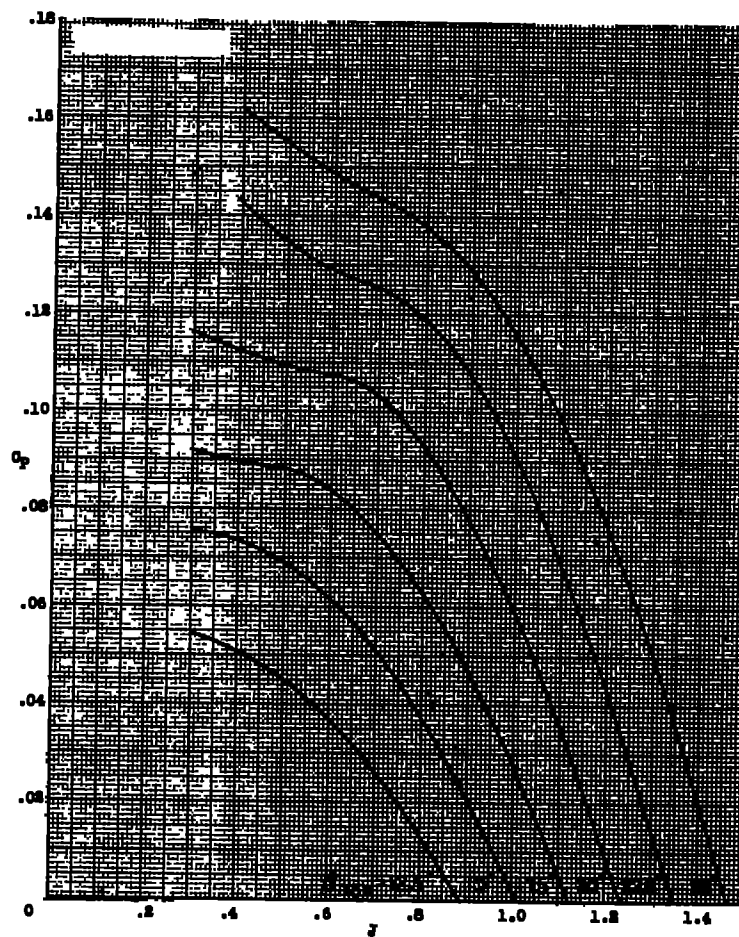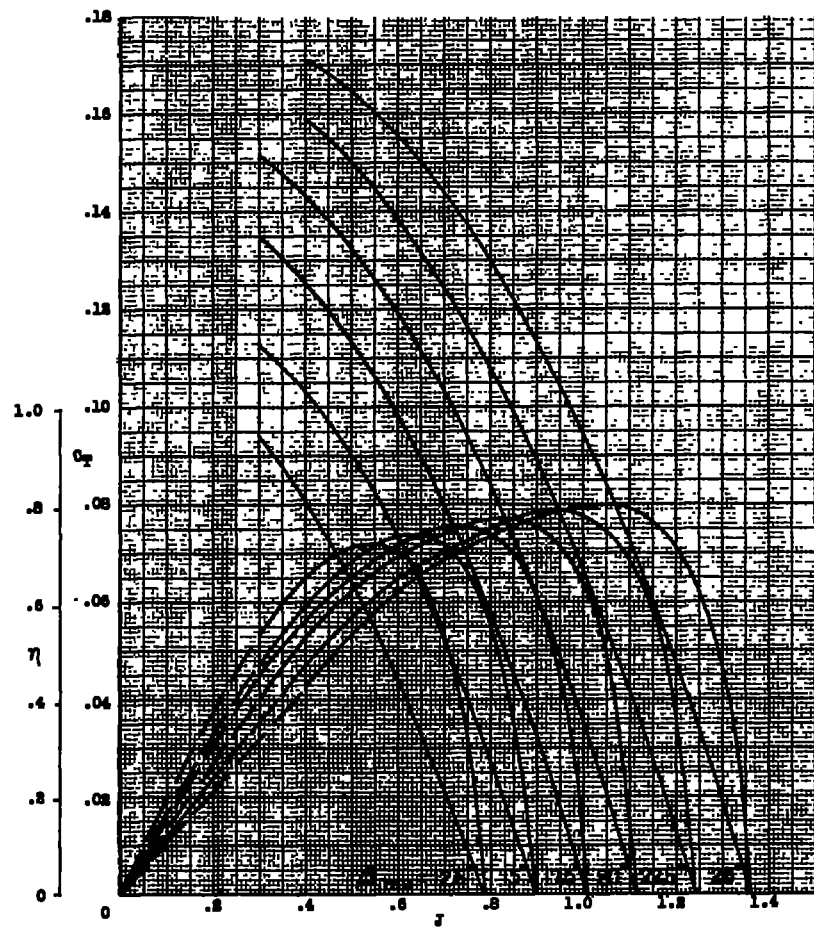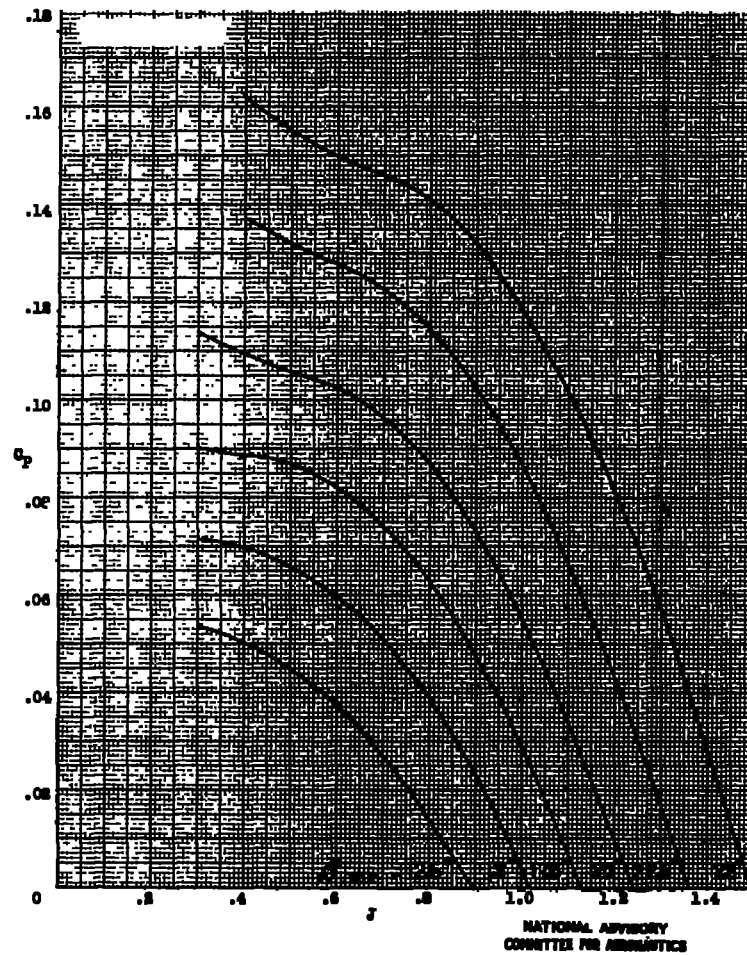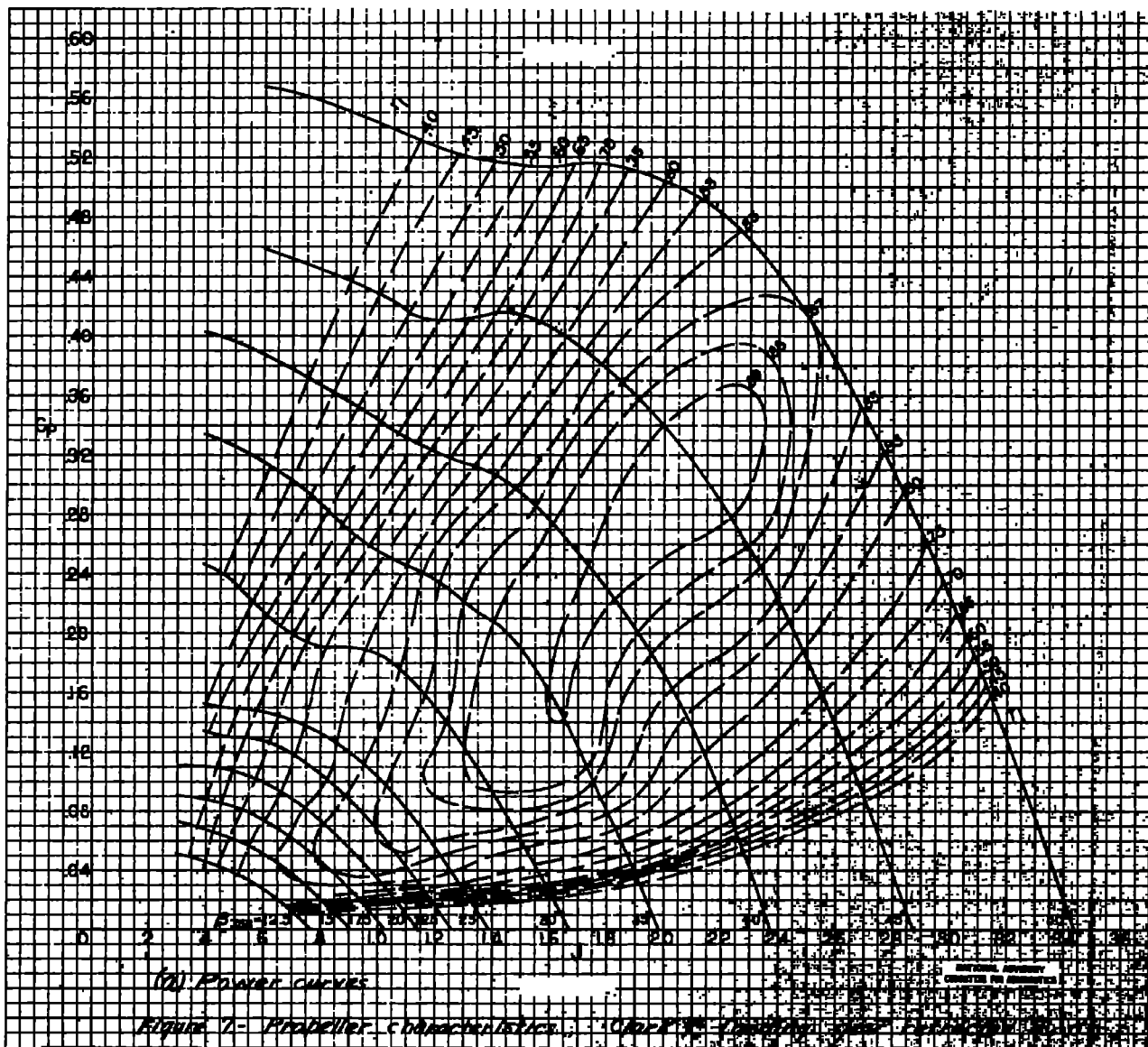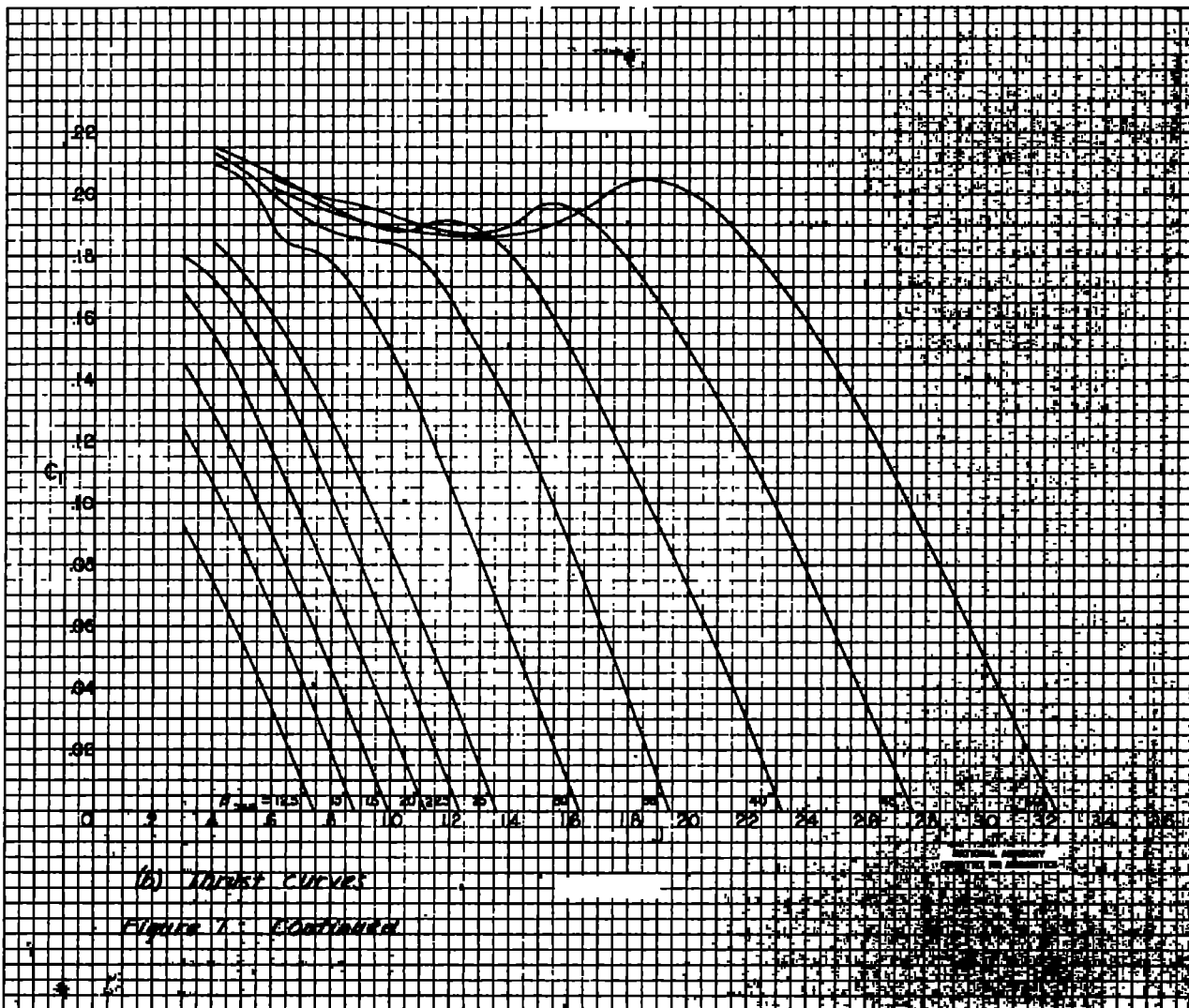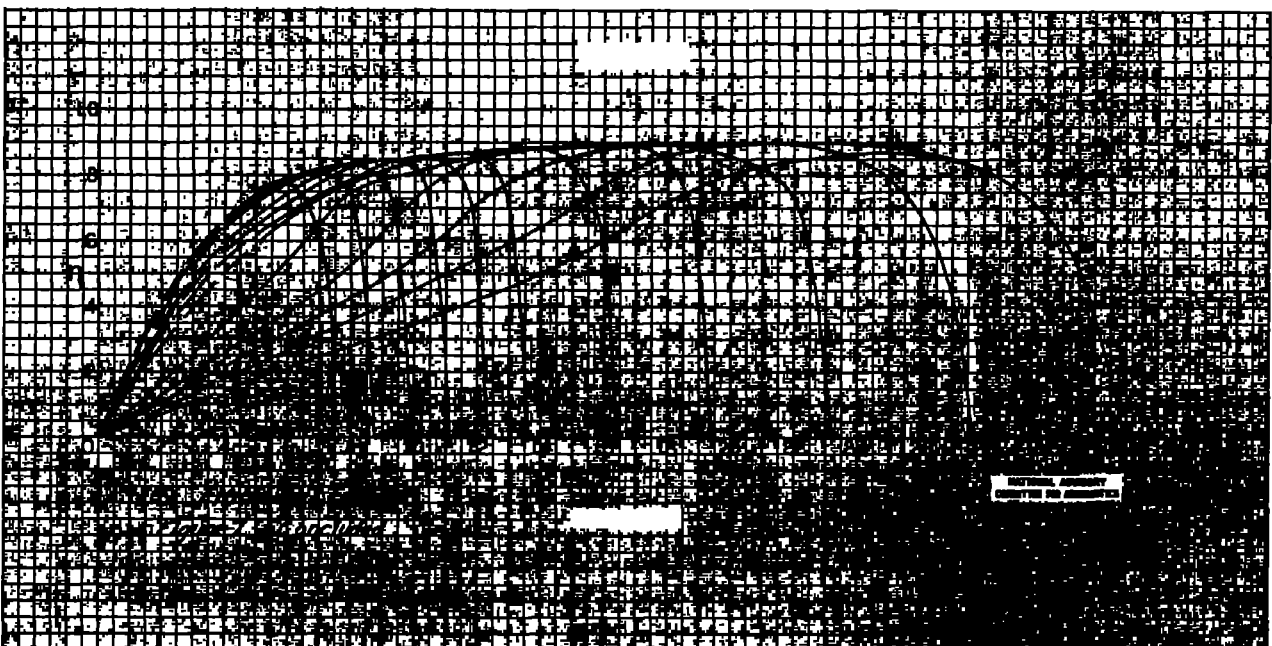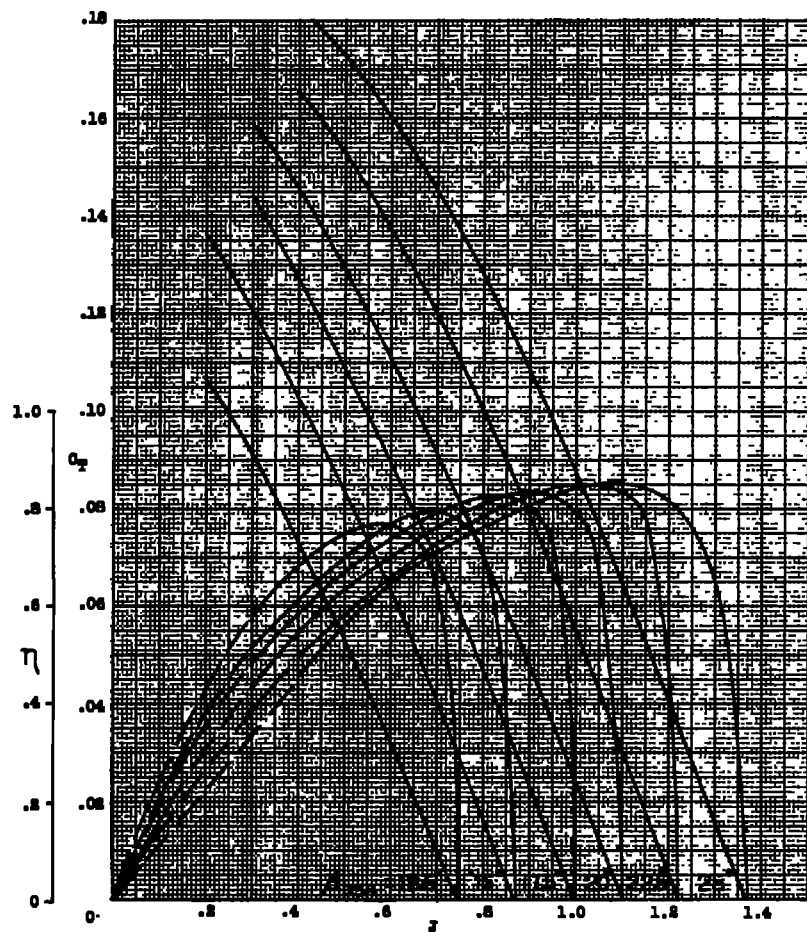
Figure 7. Continued

(a) $\delta_f = 10^\circ$

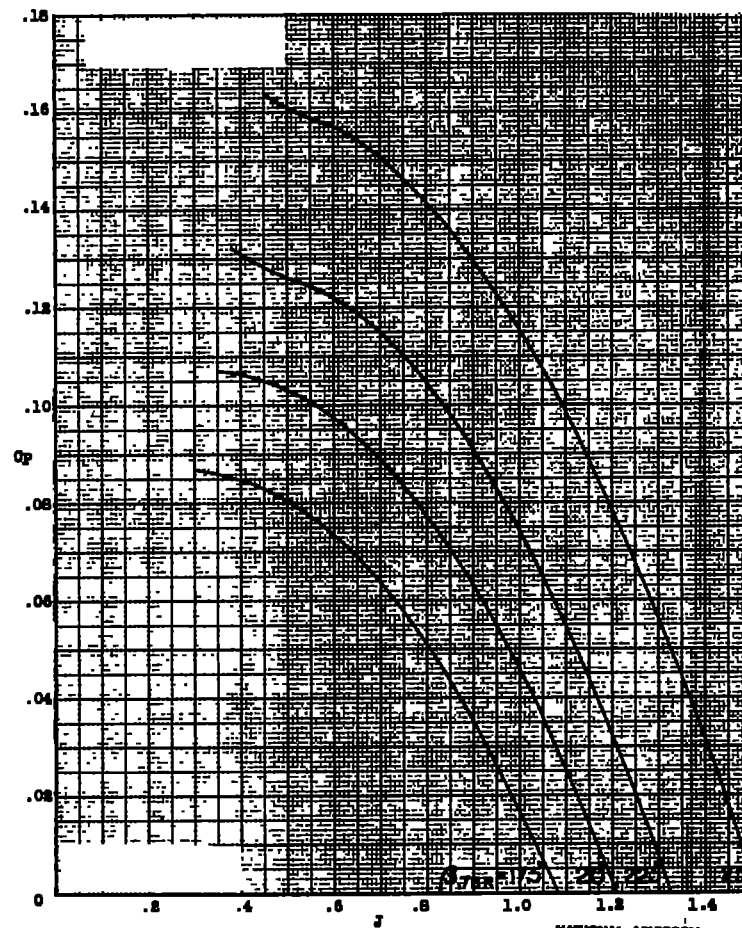Figure 8.- Propeller characteristics, Clark Y, landing gear retracted.
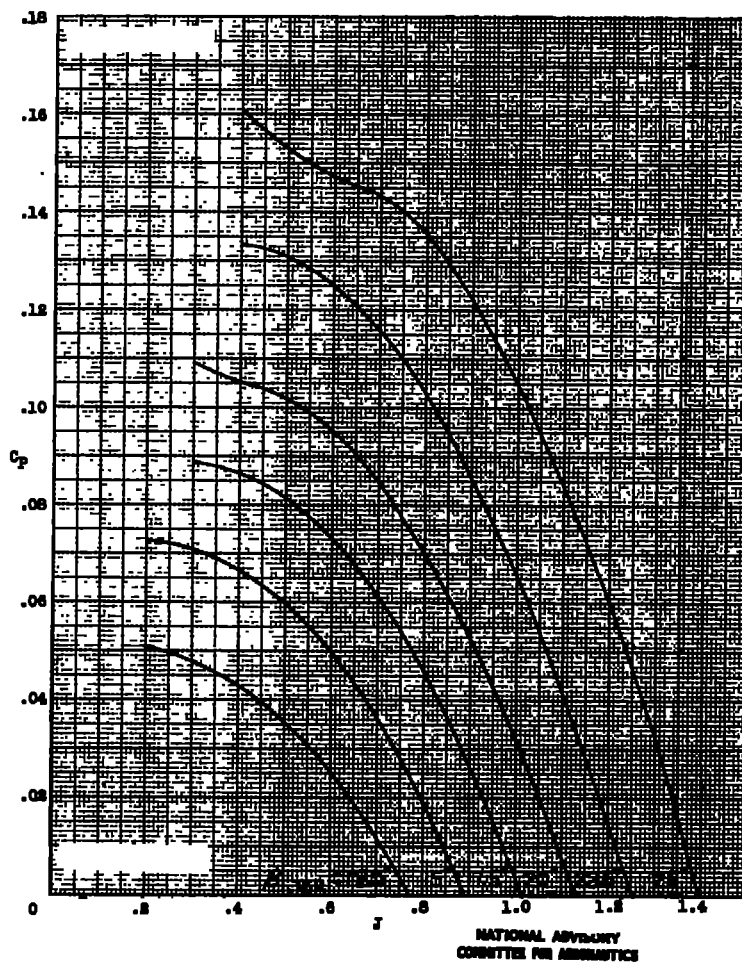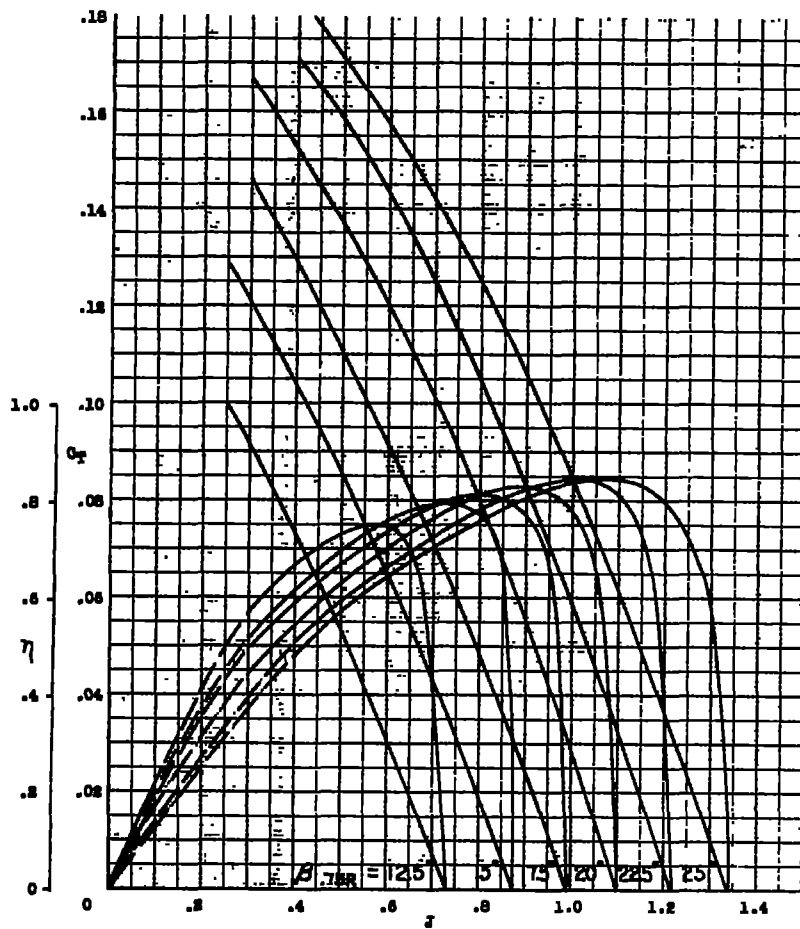
(b) $\delta_f = 20°$

Figure 8.- Continued.

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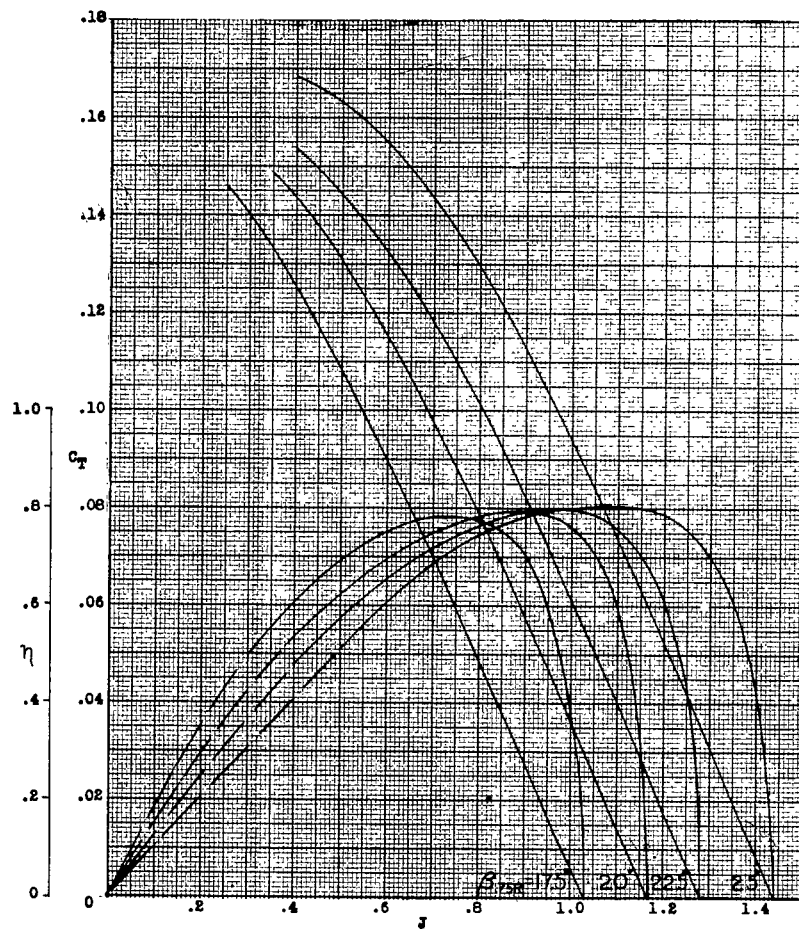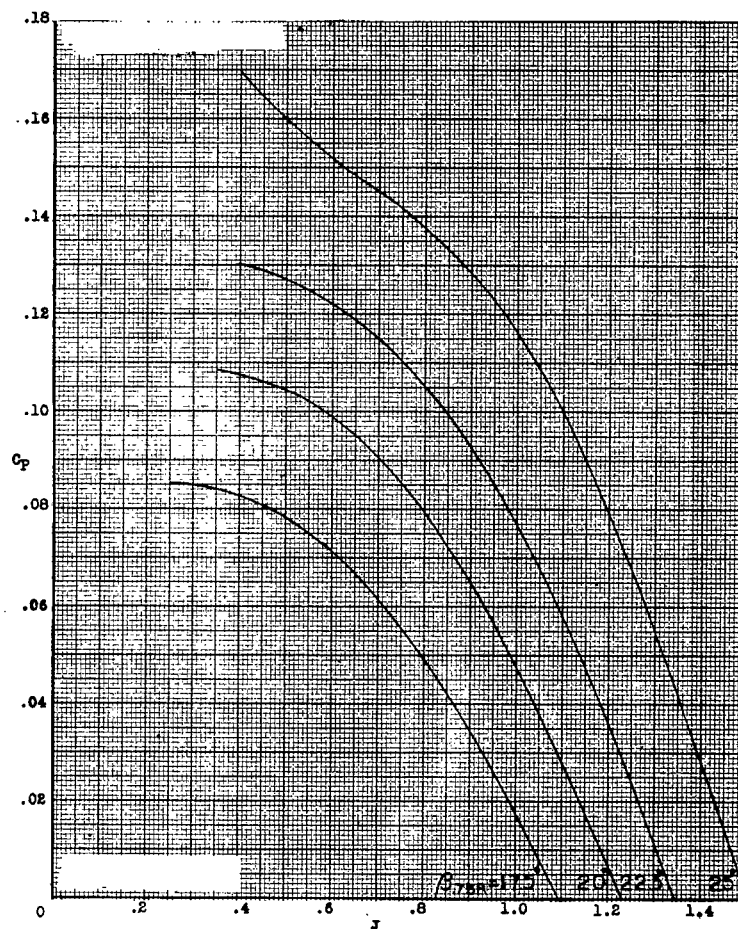COMMITTEE FOR AERONAUTICS

(c) $\delta_f = 30°$

Figure 8.- Continued.

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(d) $\delta_f = 40°$
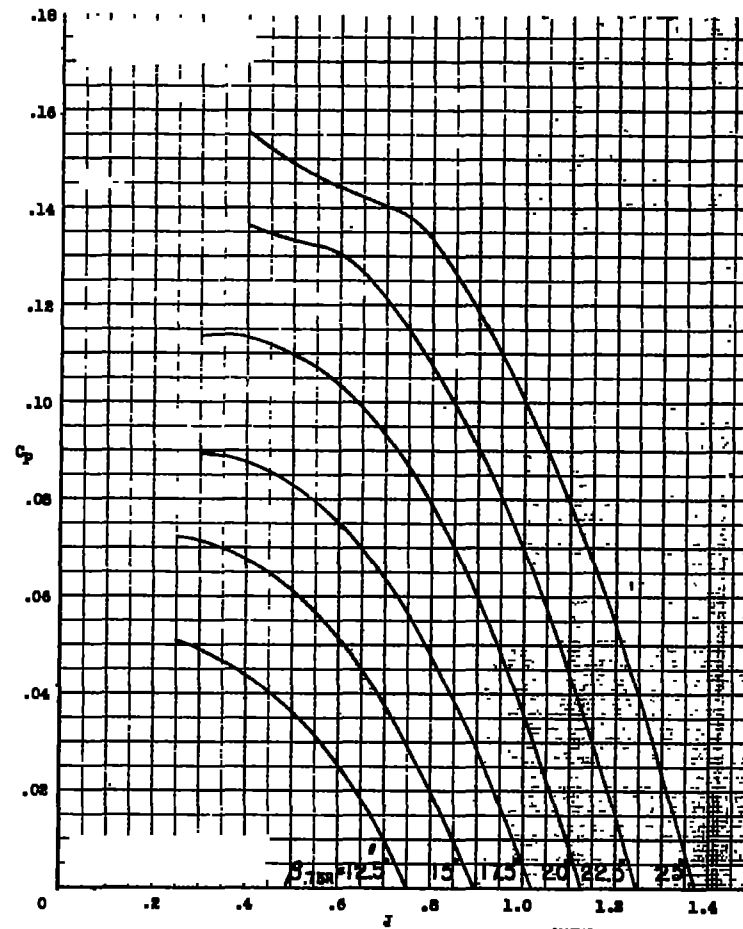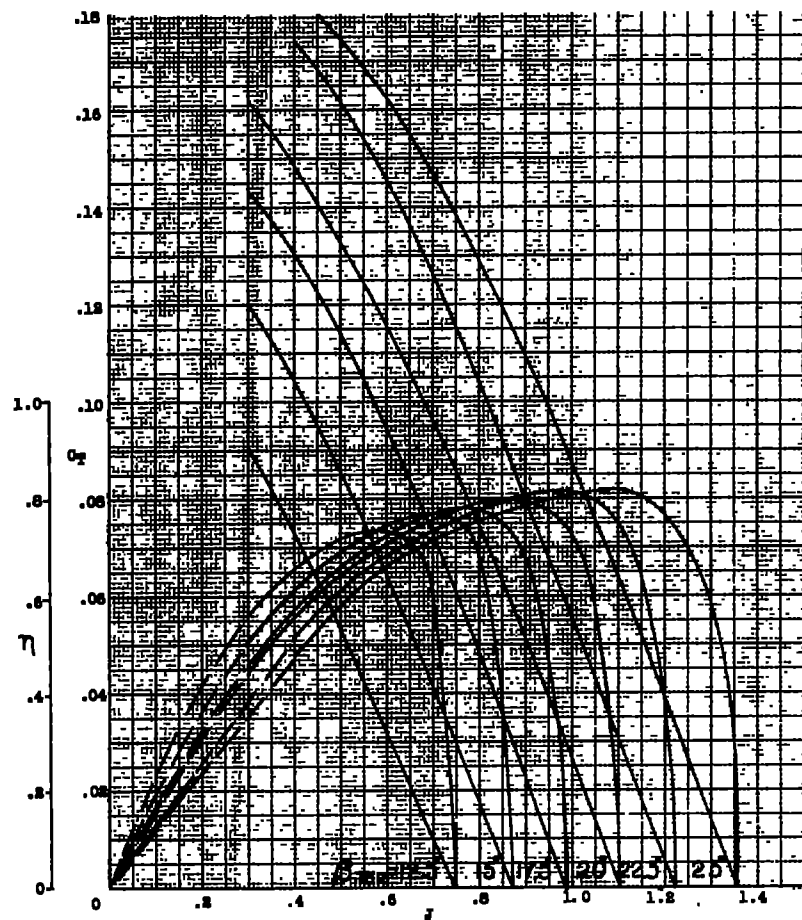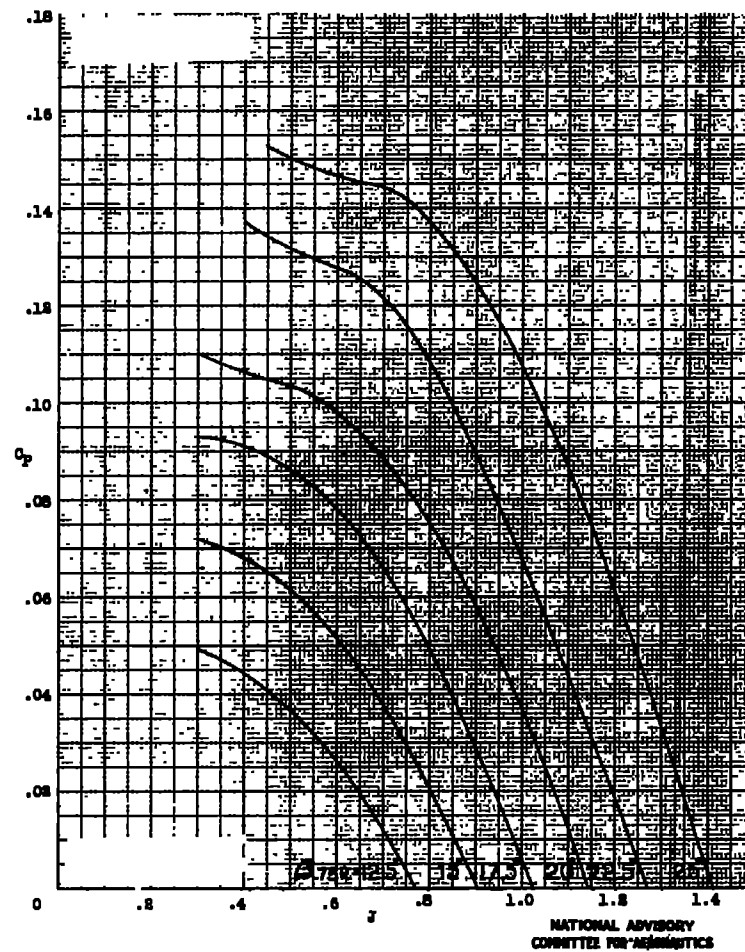
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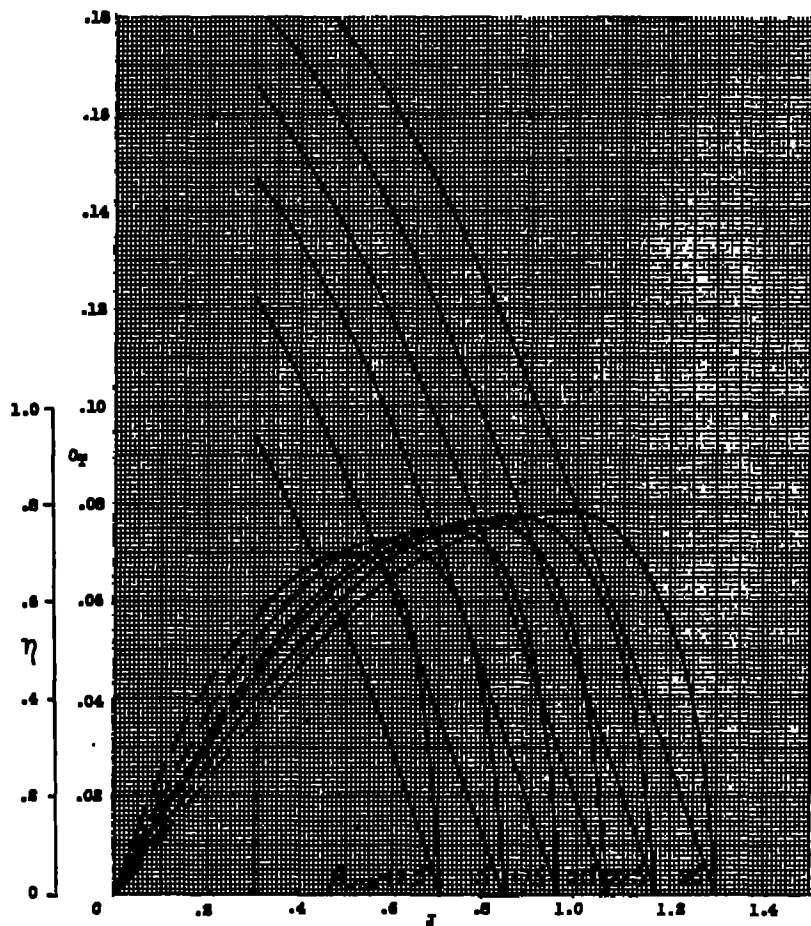
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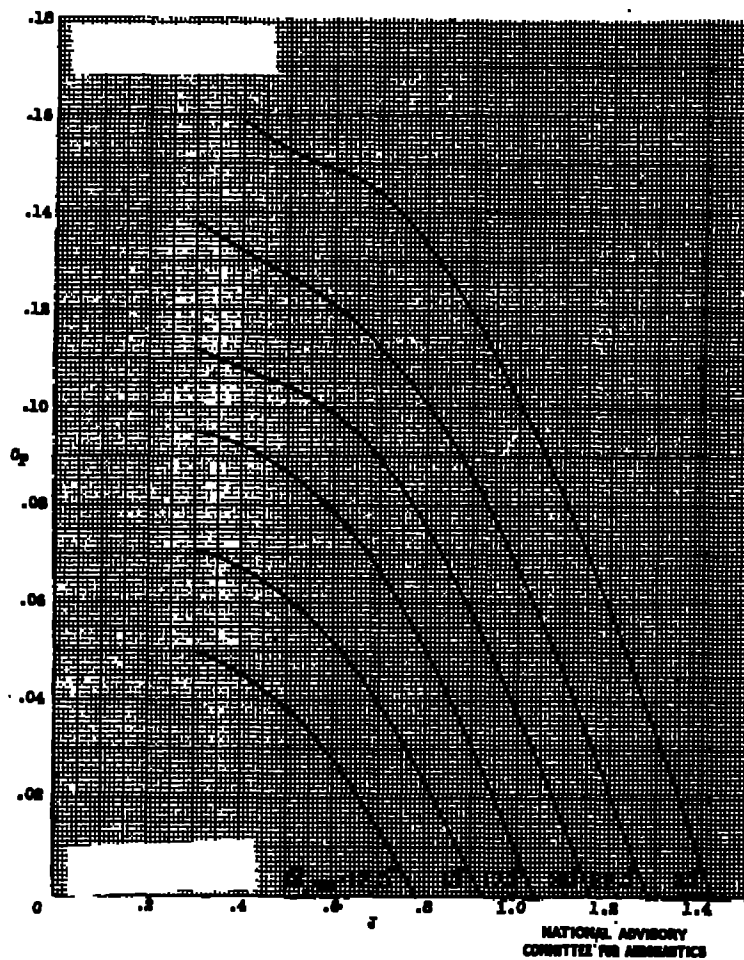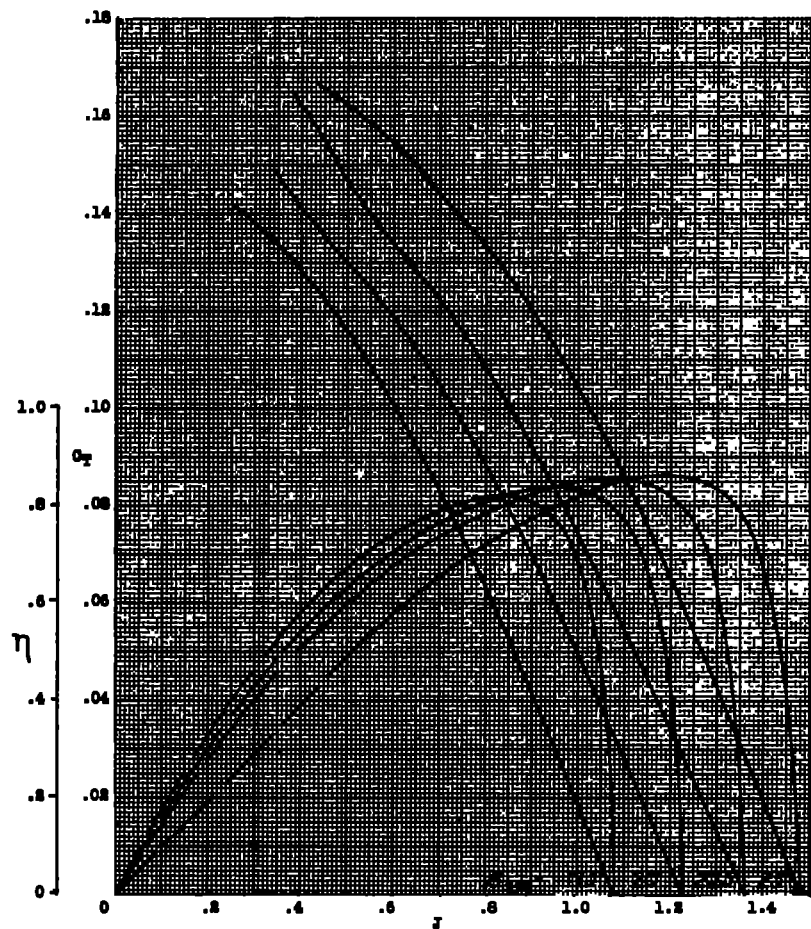
(a) $\delta_r = 0°$

Figure 9.- Propeller characteristics, 16-series, landing gear extended.

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.18

.16

.14

.12

.10 C_T

.08

.06

.04

.02

0

1.0 η

.8

.6

.4

.2

0

0   .2   .4   .6   .8   1.0   1.2   1.4

J

.18

.16 C_P

.14

.12

.10

.08

.06

.04

.02

0

.2   .4   .6   .8   1.0   1.2   1.4   1.6

J

(b) $\delta_f = 10°$

Figure 9.- Continued.

(e) $\delta_T = 20°$

Figure 9.- Continued.

(d) $\delta_f = 30°$
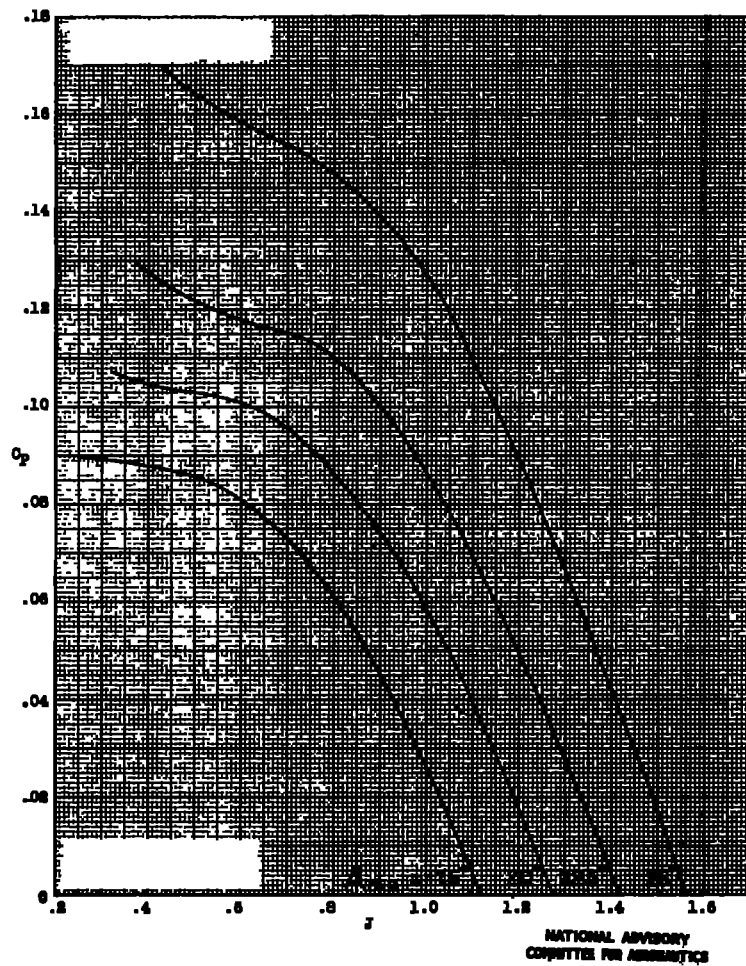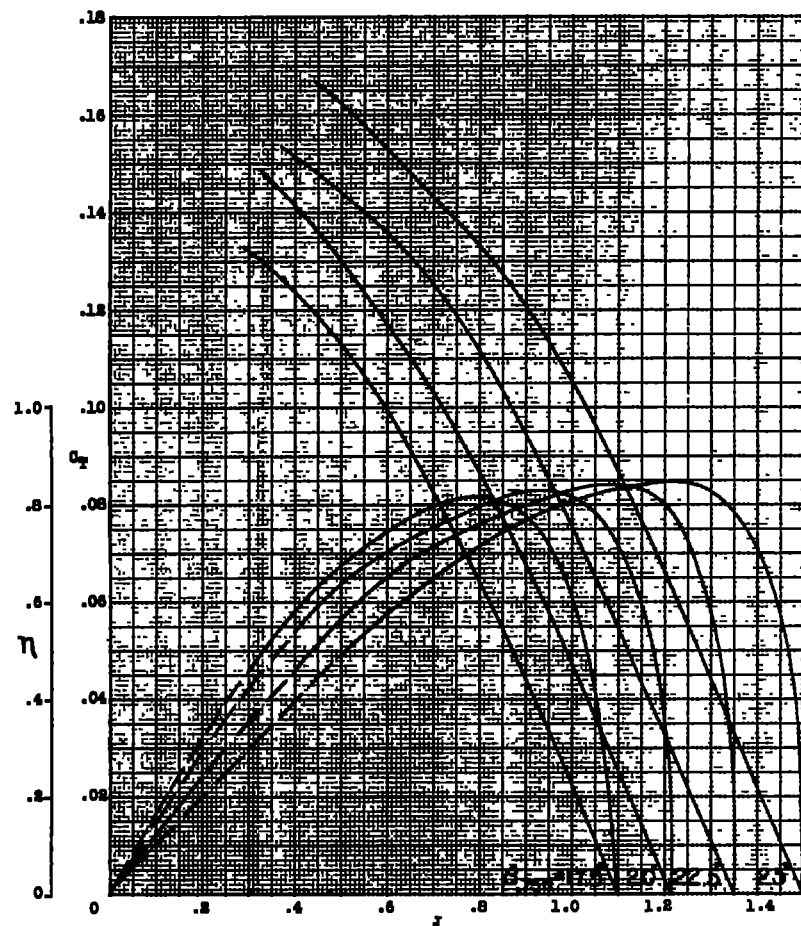
Figure 9.- Continued.

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C_T

C_P

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η

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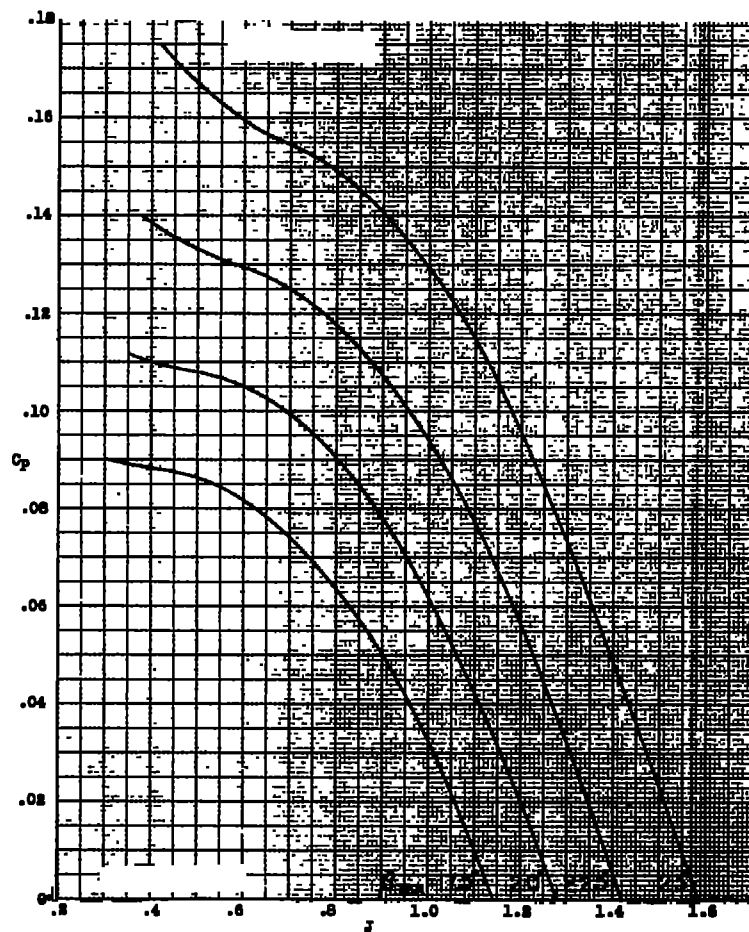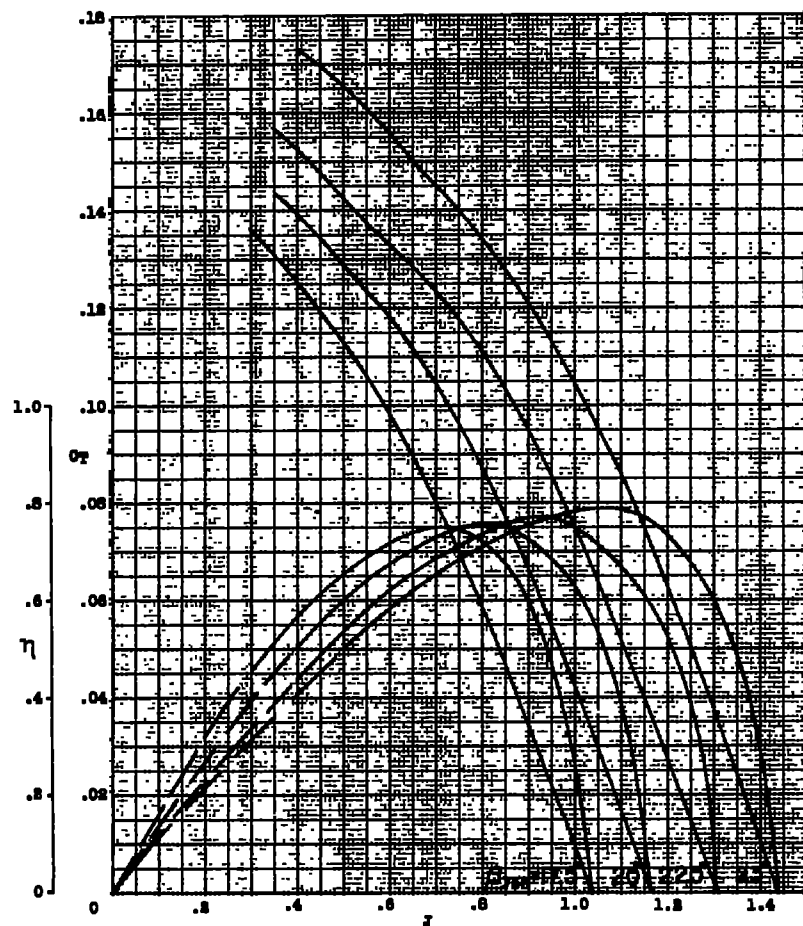
(e) $\delta_f = 40°$

Figure 9.— Concluded.
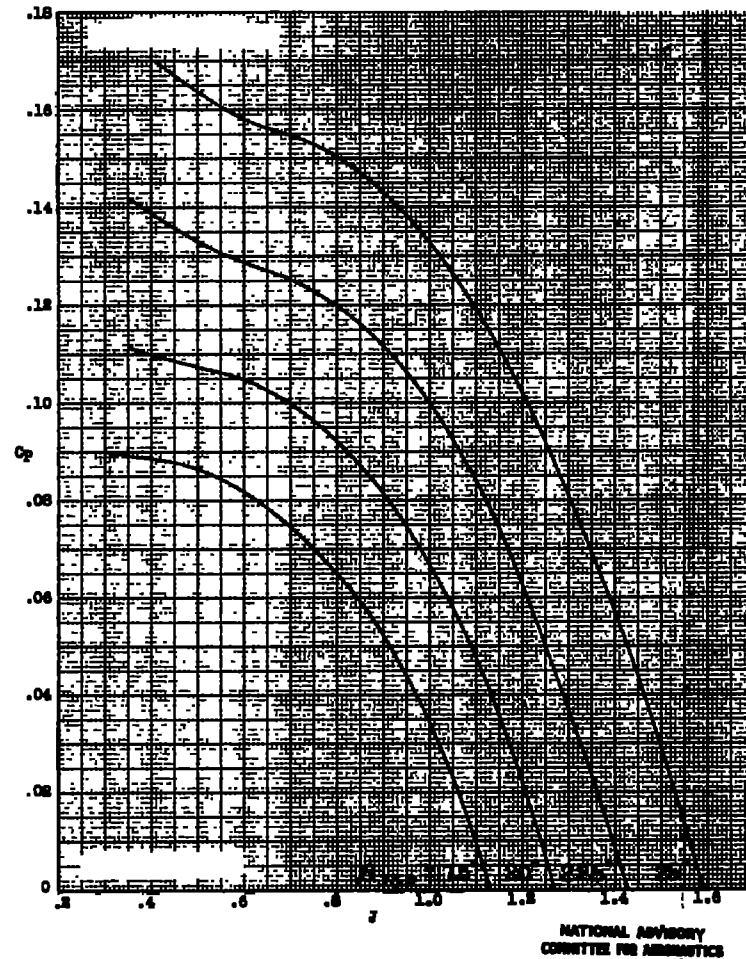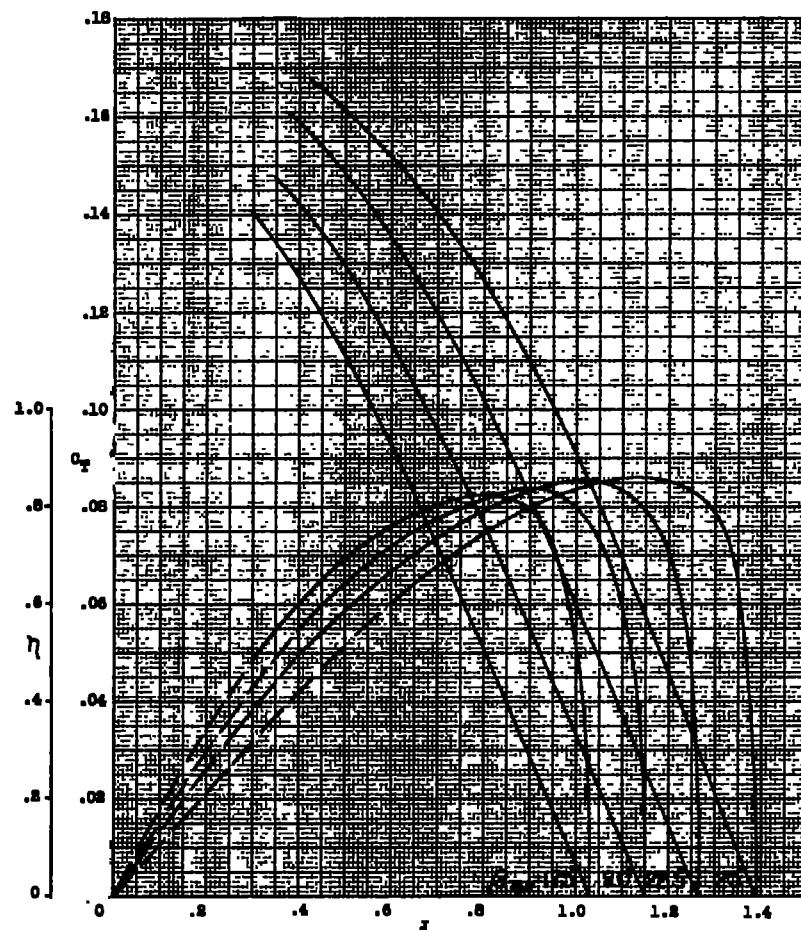
(a) $\delta_f = 0^\circ$

Figure 10.- Propeller characteristics, Clark Y, landing gear extended.
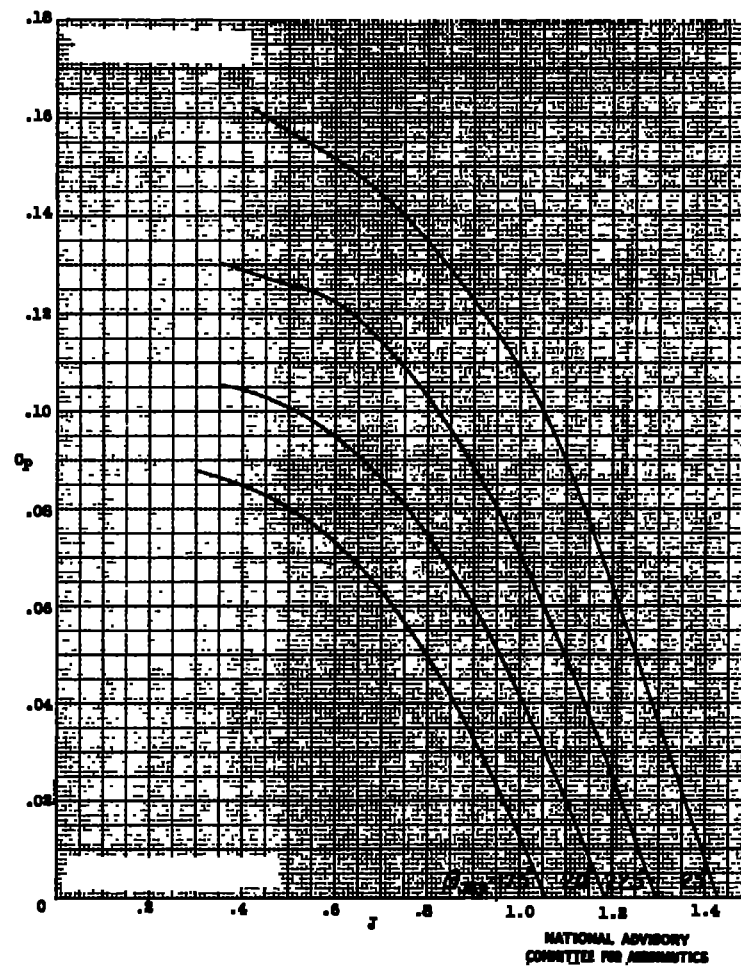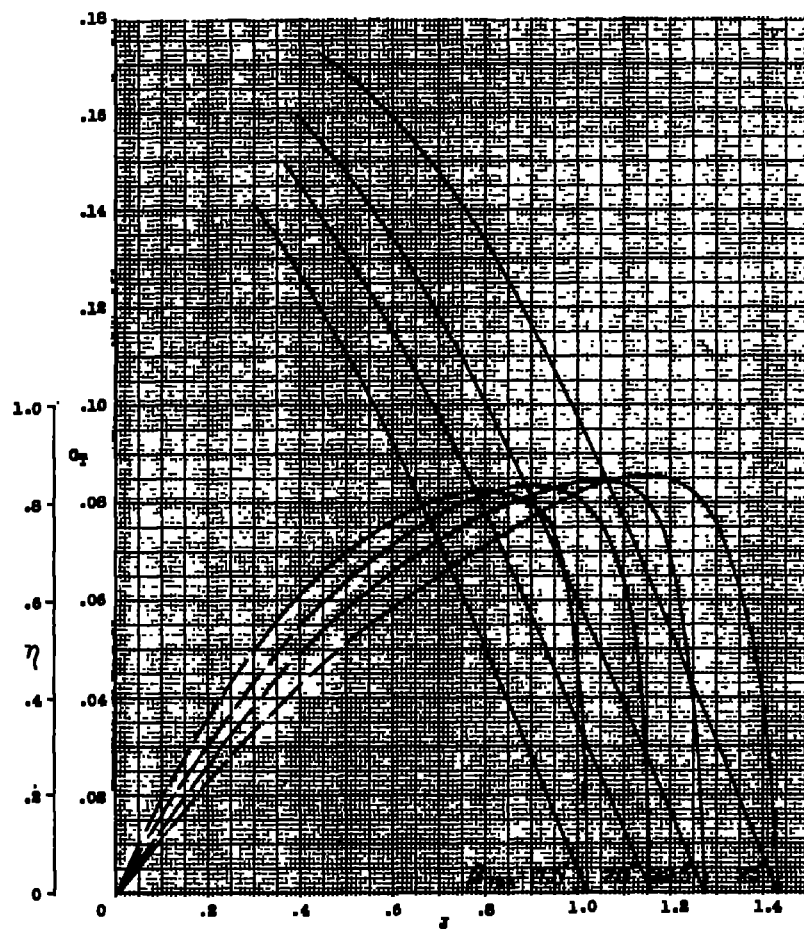
(b) $\delta_r = 10°$

Figure 10.- Continued.

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(e) $\delta_r = 20°$

Figure 10.- Continued.
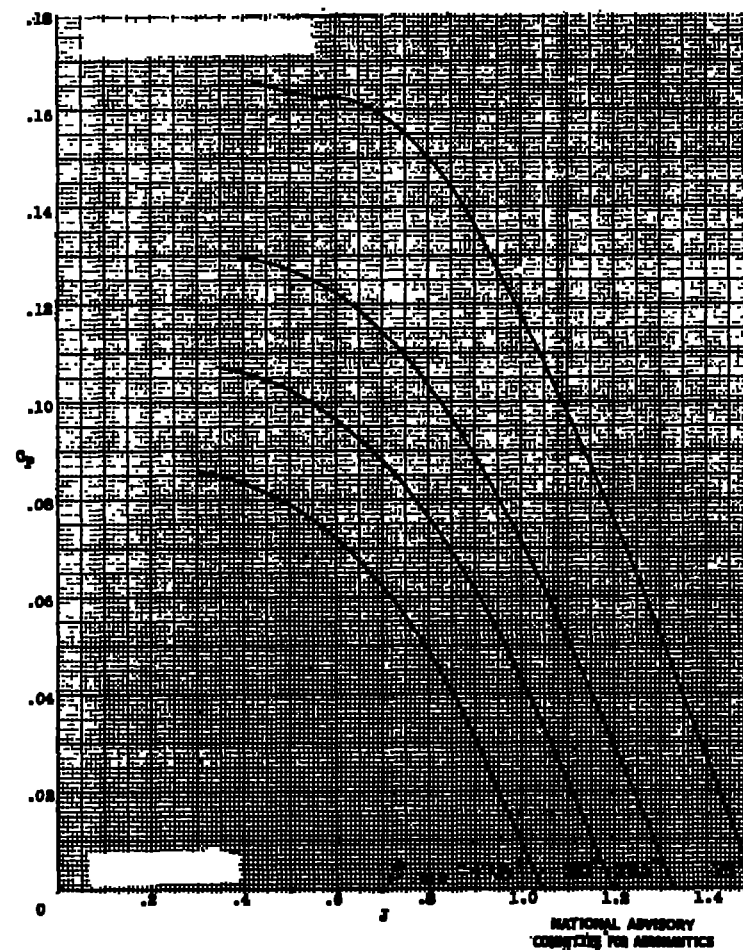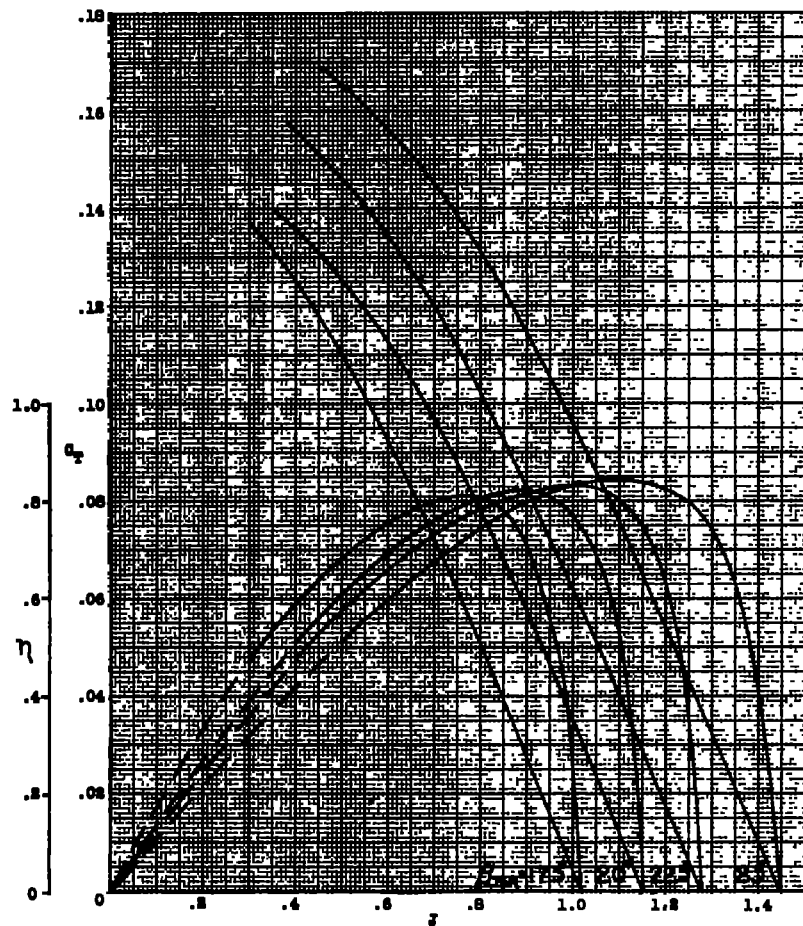
(d) $\delta_f = 30°$

Figure 10.- Continued.

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(e) $\delta_f = 40°$
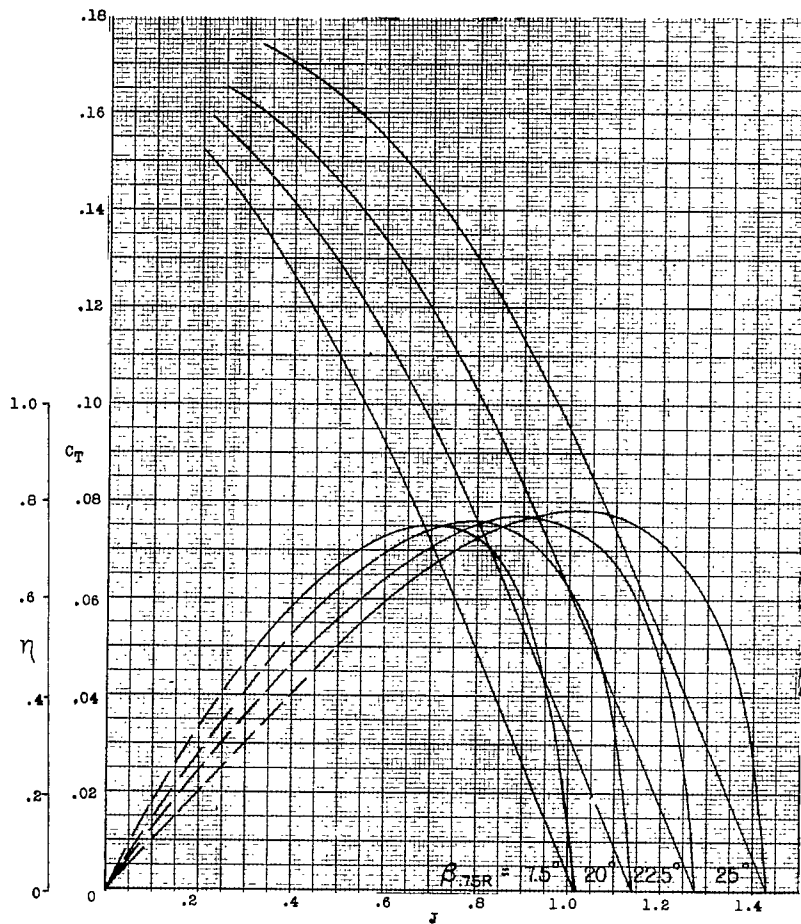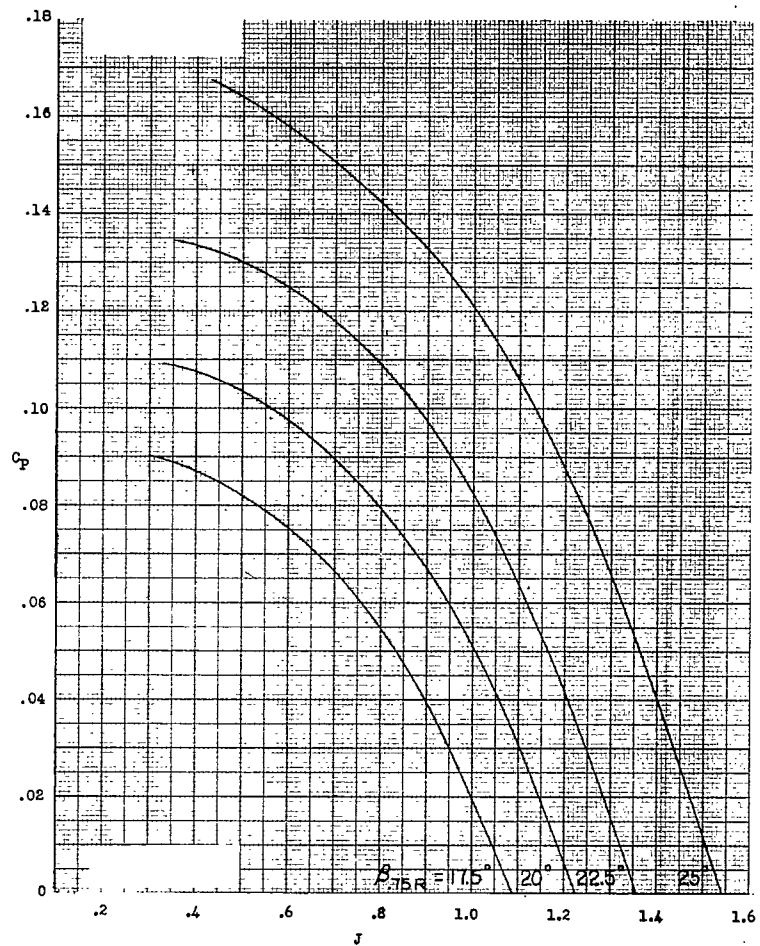
Figure 10.- Concluded.

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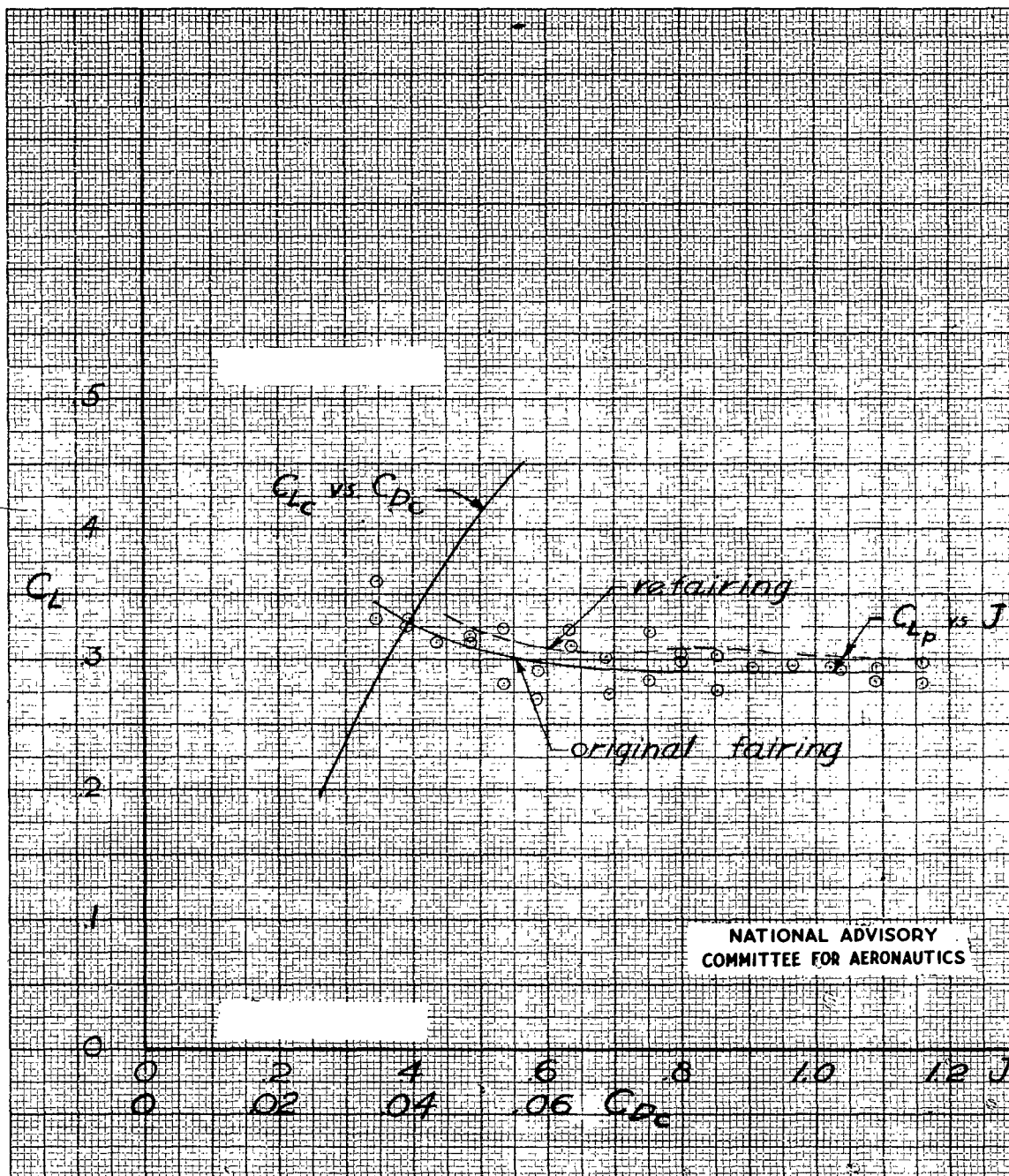
Figure 11.- Typical refairing necessary to obtain faired
propeller characteristics; 16-series; $\delta_f = 10°$; β, 20°;
landing gear retracted.
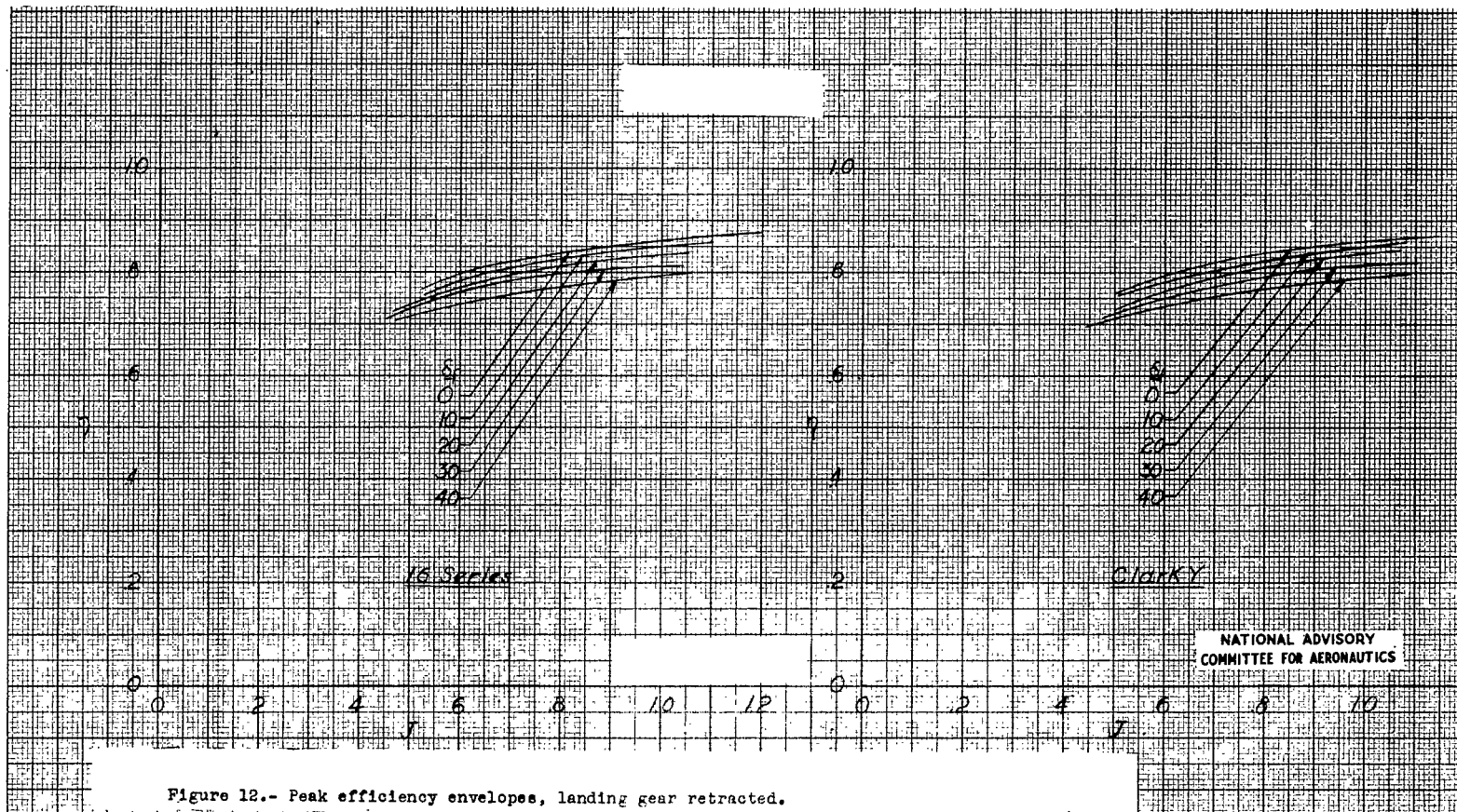
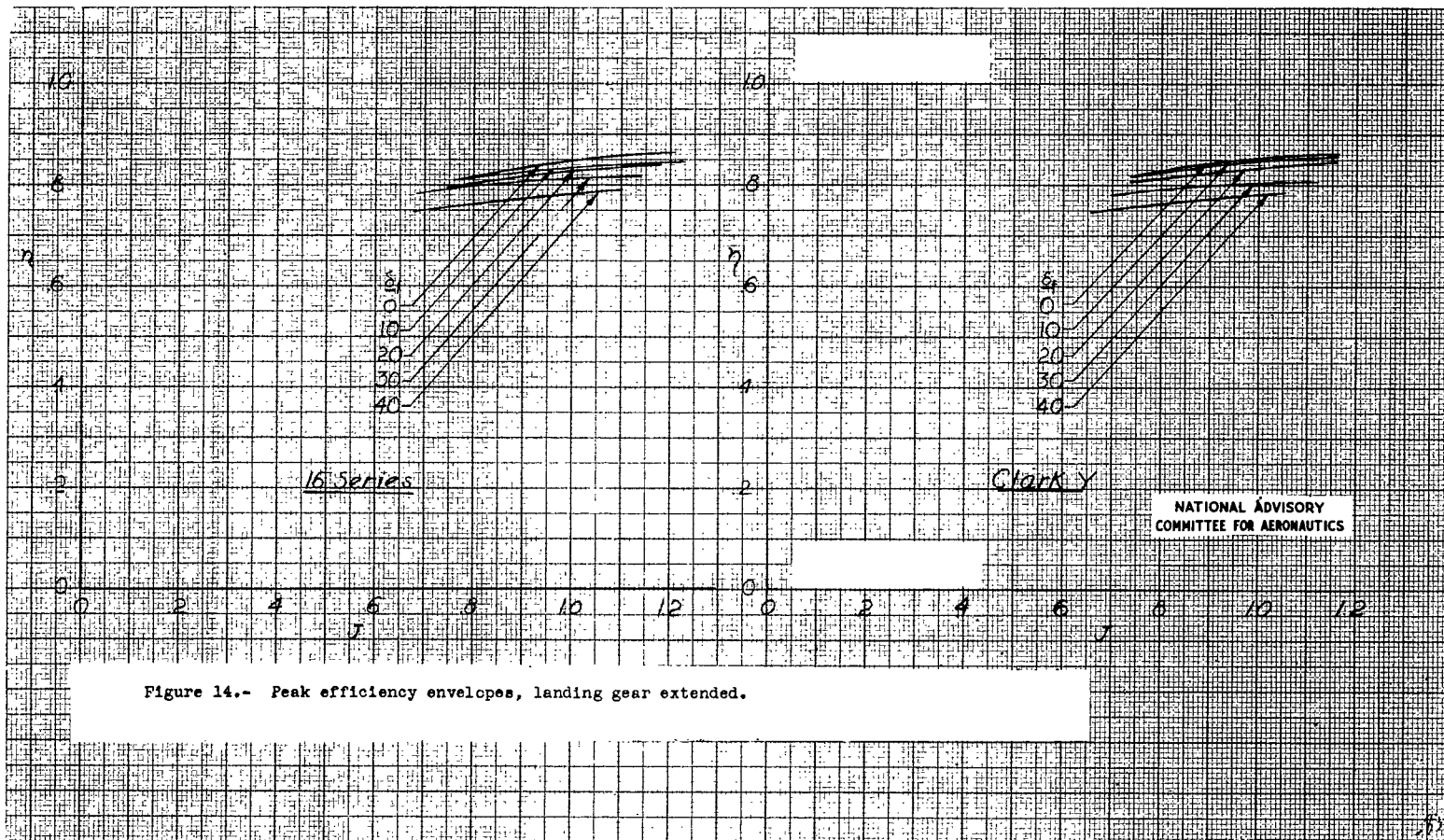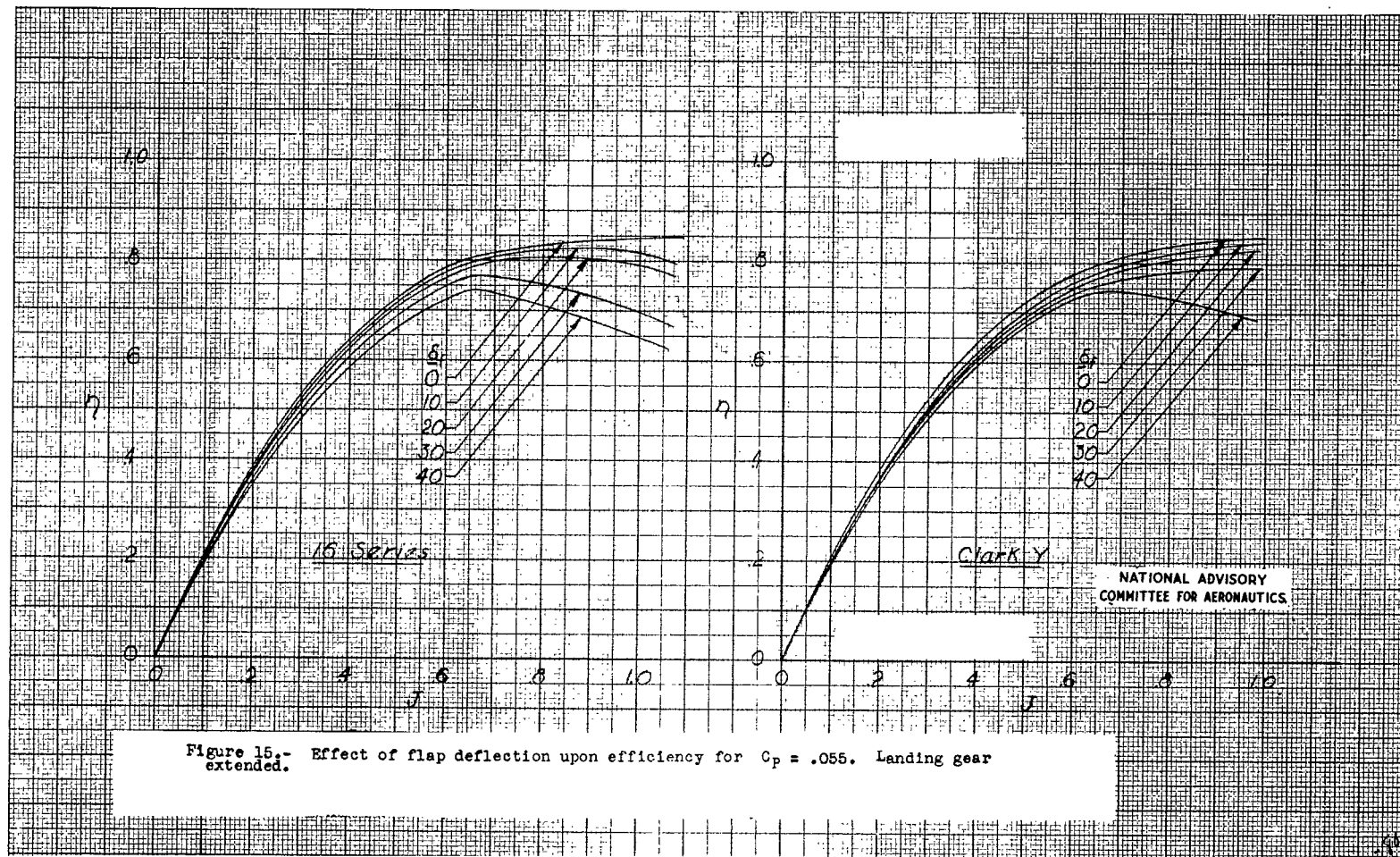Figure 12.- Peak efficiency envelopes, landing gear retracted.

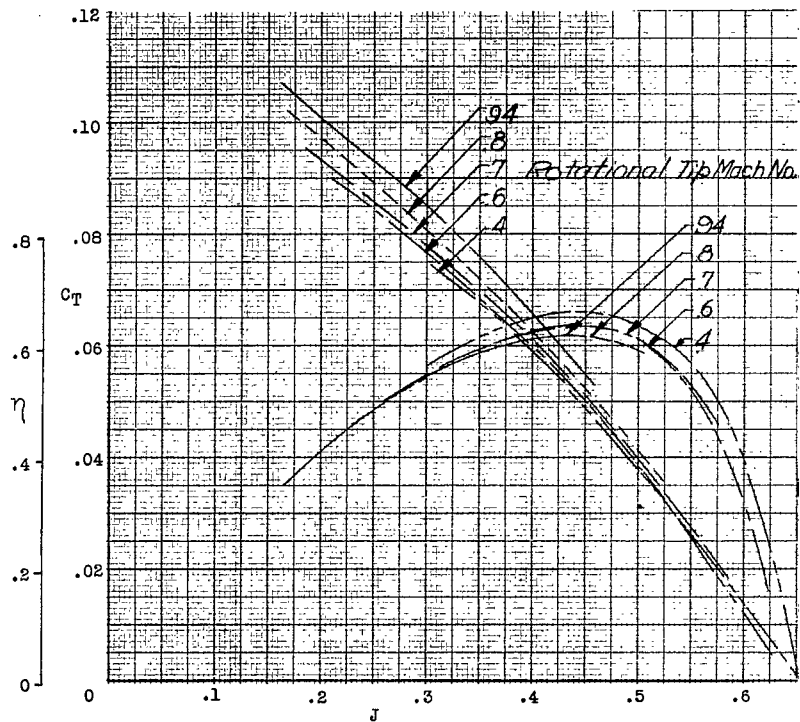Figure 13.- Effect of flap deflection upon efficiency for C_p = .055. Landing gear retracted.
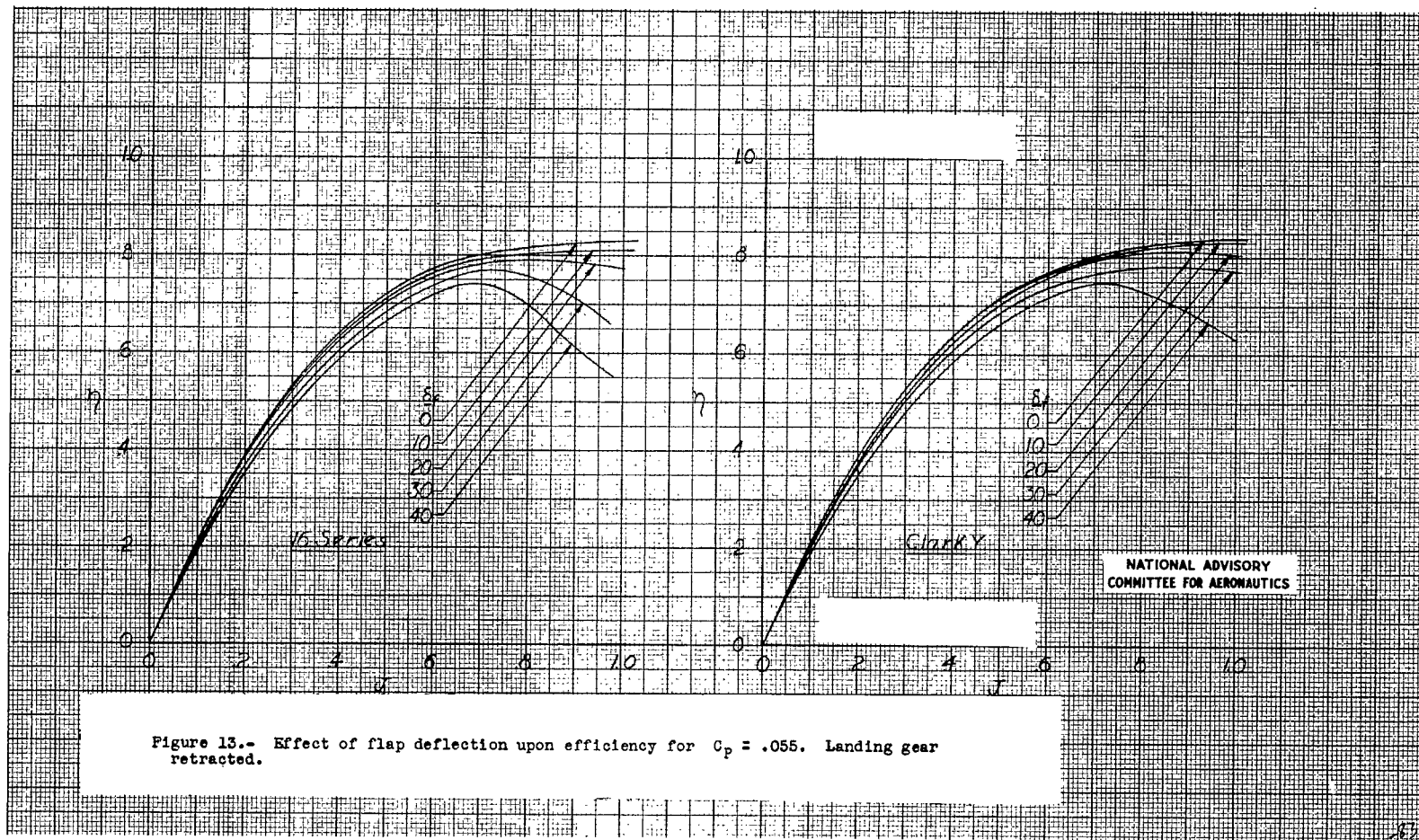
Figure 14.- Peak efficiency envelopes, landing gear extended.

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Figure 15.- Effect of flap deflection upon efficiency for $C_p = .055$. Landing gear extended.

· (a) 16-series.

Figure 16.- Effect of tip speed upon propeller characteristics. Landing gear retracted;
  β, 10°; δ_f, 0°.

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(b) Clark Y
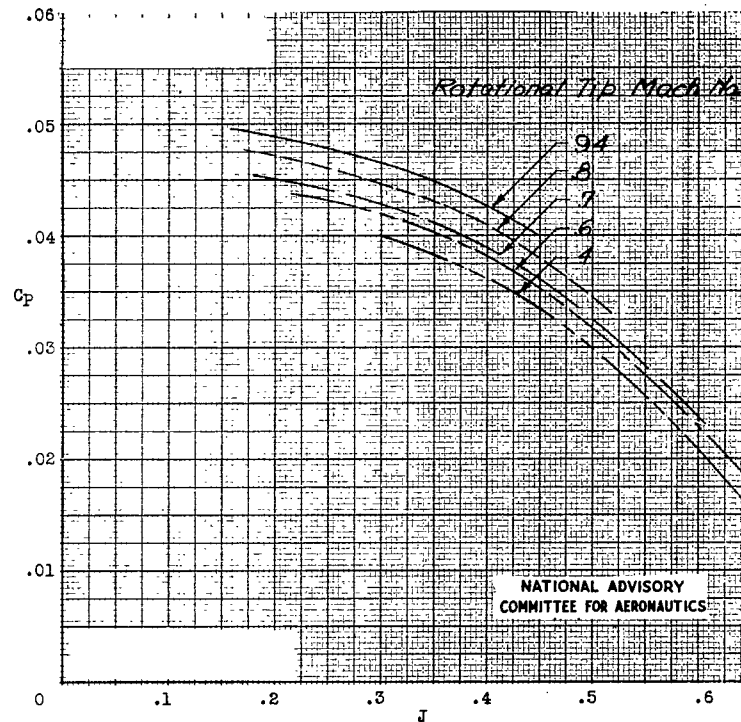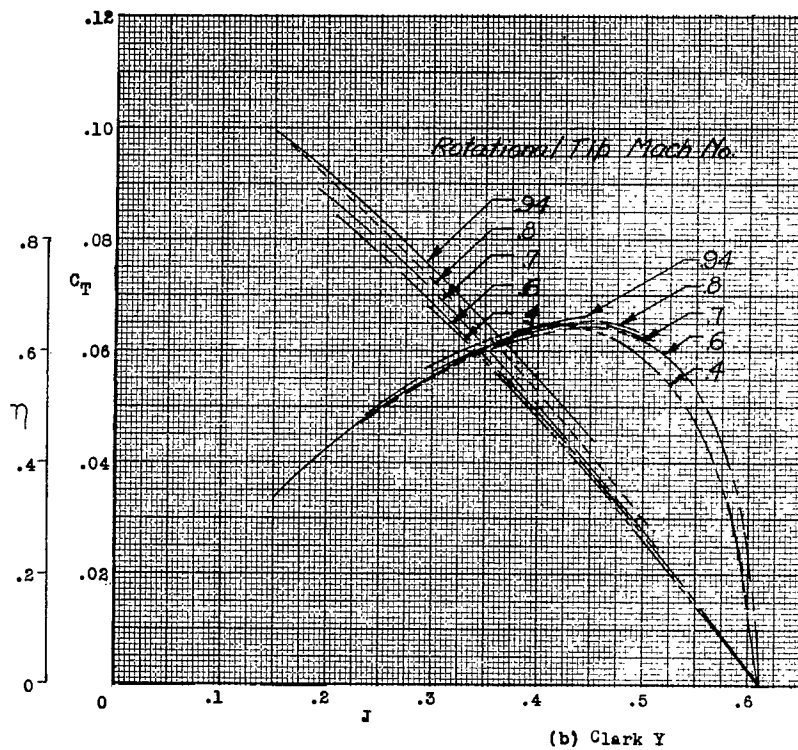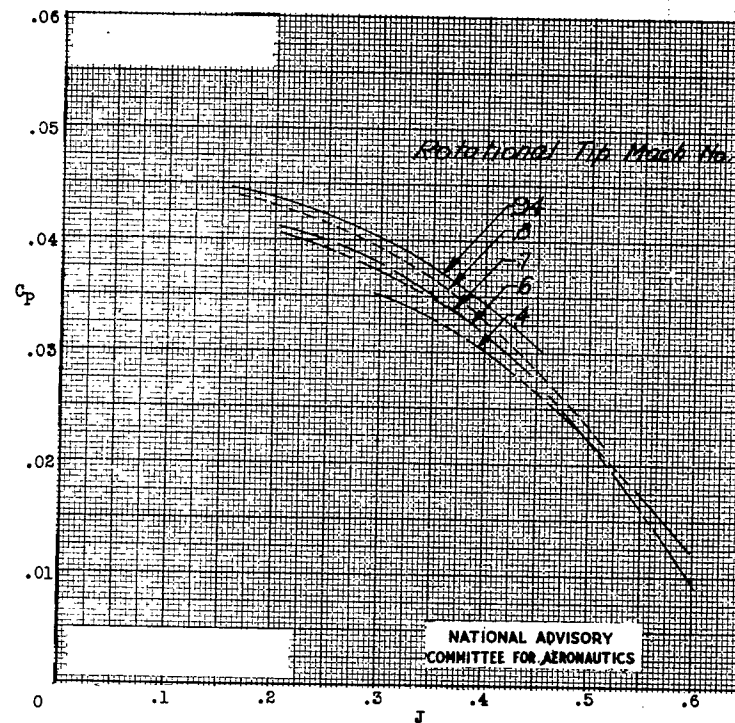
Figure 16.- Concluded.
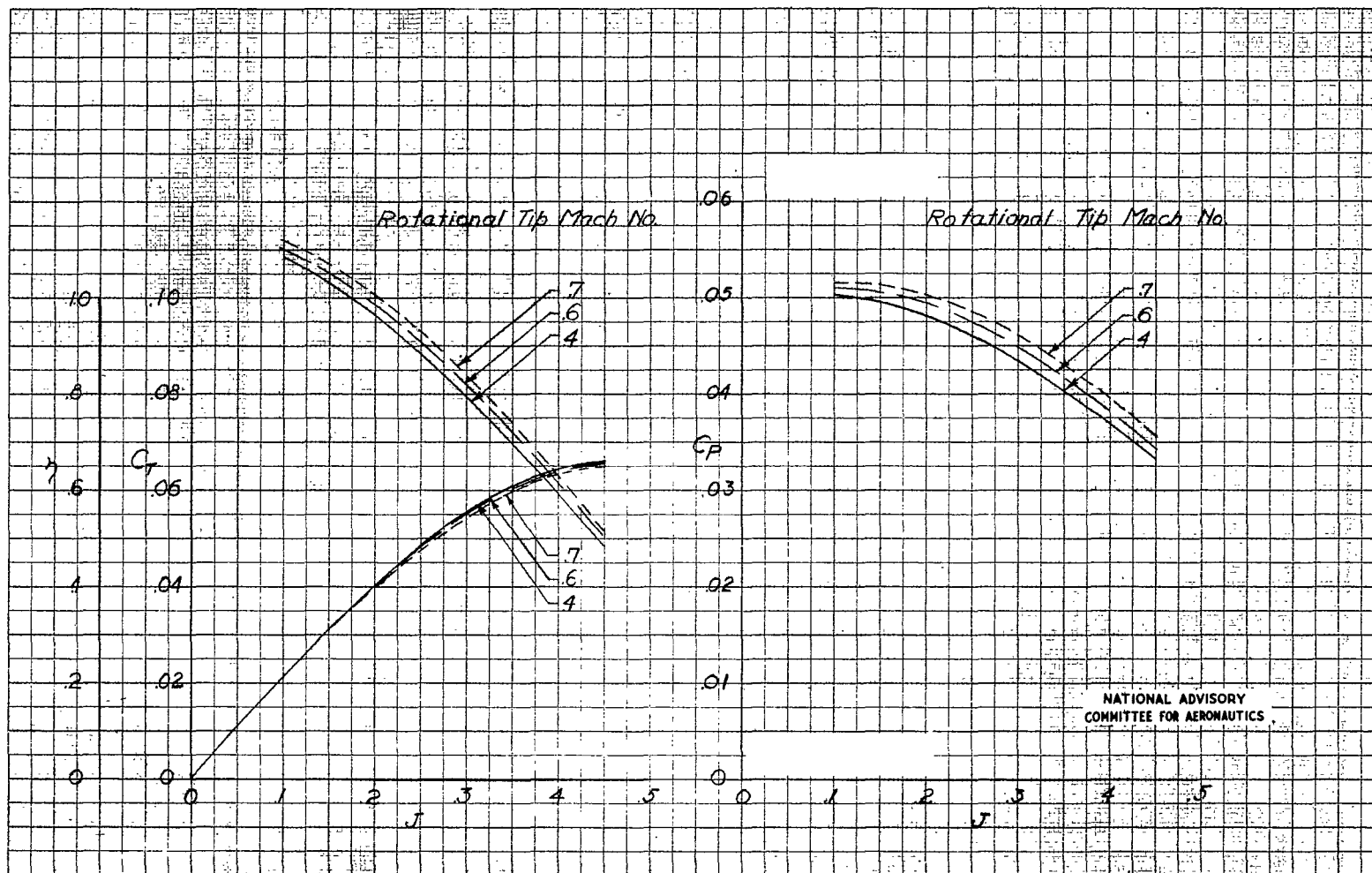
Figure 17.- Calculated propeller characteristics for 16-series propeller for 3 tip speeds.
β , 10°.